



US007271580B1

(12) **United States Patent**
Fenske et al.

(10) **Patent No.:** **US 7,271,580 B1**
(45) **Date of Patent:** ***Sep. 18, 2007**

(54) **APPARATUS AND METHOD FOR
PROGRAMMABLE TRIP SETTINGS IN A
FAULTED CIRCUIT INDICATOR**

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

This patent is subject to a terminal dis-
claimer.

(21) Appl. No.: **10/988,007**

(22) Filed: **Nov. 12, 2004**

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/454,851,
filed on Jun. 4, 2003, now Pat. No. 6,894,478, and a
continuation-in-part of application No. 10/454,850,
filed on Jun. 4, 2003, now Pat. No. 7,023,691, and a
continuation-in-part of application No. 10/455,670,
filed on Jun. 4, 2003, now Pat. No. 7,106,048, and a
continuation-in-part of application No. 10/454,847,
filed on Jun. 4, 2003, now Pat. No. 6,949,921, and a
continuation-in-part of application No. 10/280,322,
filed on Oct. 25, 2002, now abandoned, and a con-
tinuation-in-part of application No. 10/280,219, filed
on Oct. 25, 2002, now Pat. No. 6,734,662, and a
continuation-in-part of application No. 10/280,141,
filed on Oct. 25, 2002, now Pat. No. 7,053,601, and
a continuation-in-part of application No. 10/280,329,
filed on Oct. 25, 2002, and a continuation-in-part of
application No. 10/280,195, filed on Oct. 25, 2002,
now abandoned, and a continuation-in-part of appli-
cation No. 10/280,328, filed on Oct. 25, 2002, now
Pat. No. 6,822,576.

(60) Provisional application No. 60/519,106, filed on Nov.
12, 2003, provisional application No. 60/339,412,
filed on Oct. 26, 2001, provisional application No.
60/337,631, filed on Oct. 26, 2001, provisional appli-
cation No. 60/339,256, filed on Oct. 26, 2001, pro-
visional application No. 60/337,438, filed on Oct. 26,
2001, provisional application No. 60/339,514, filed
on Oct. 26, 2001, provisional application No. 60/337,
632, filed on Oct. 26, 2001.

(51) **Int. Cl.**
G01R 31/00 (2006.01)

(52) **U.S. Cl.** **324/127; 324/126; 324/117 R**

(58) **Field of Classification Search** **324/126-127,
324/130-133, 509-510, 532; 340/650, 664;
361/42, 35, 38, 59; 702/191**

See application file for complete search history.

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Manzo, Cummings & Mehler, Ltd.

(57) **ABSTRACT**

A fault indicator for indicating the occurrence of a fault in
an electrical conductor is programmable, such as in the field,
by placing a magnet in proximity to the housing of the fault
indicator. A data processor senses the changed state of a
magnetic switch and, after a predetermined delay, initiates a
programming routine to enable selection of one of a plurality
of trip settings for the fault indicator. During programming,
display LEDs flash once for programming of the first trip
setting, twice for setting of the second trip setting, and so
forth. Removal of the magnet from proximity to the fault
indicator while at the desired trip setting will result in
programming of the fault indicator to that trip setting.

29 Claims, 15 Drawing Sheets

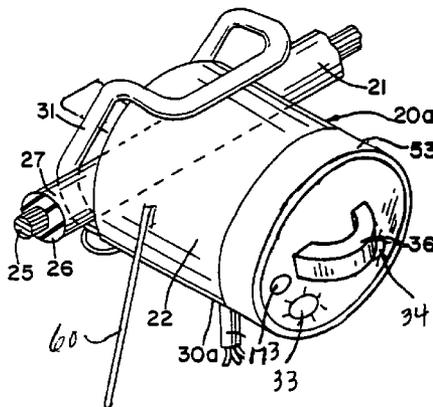


FIG. 1

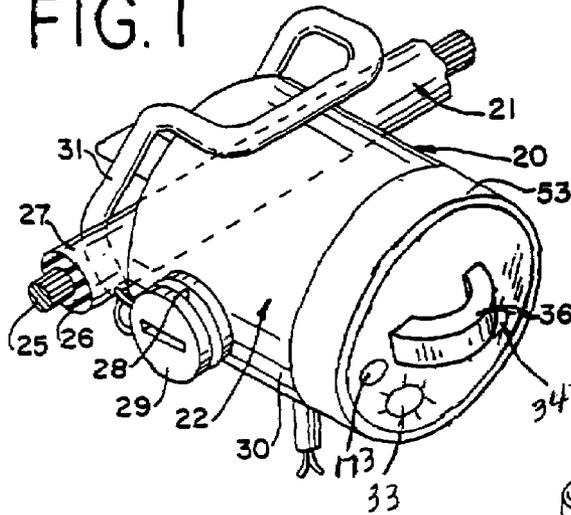


FIG. 2

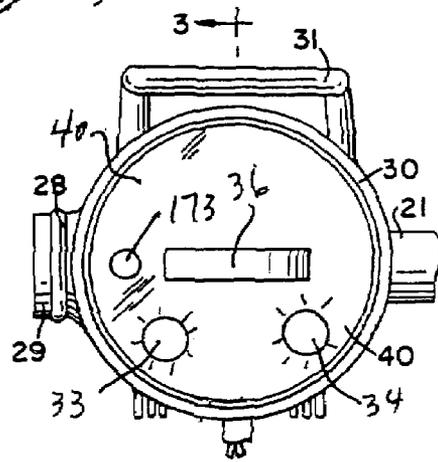


FIG. 3

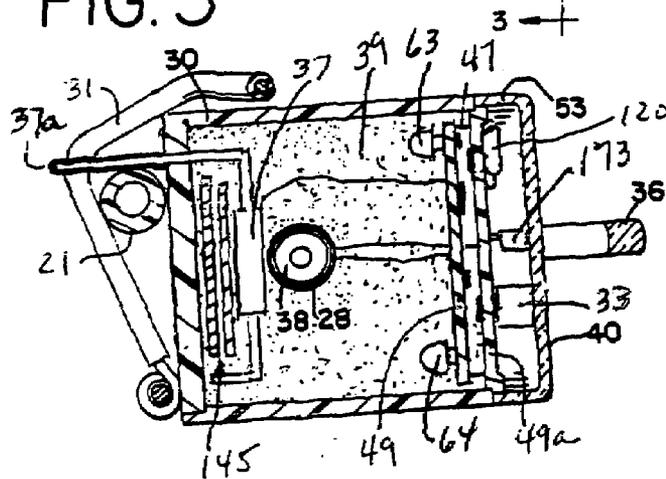


FIG. 4

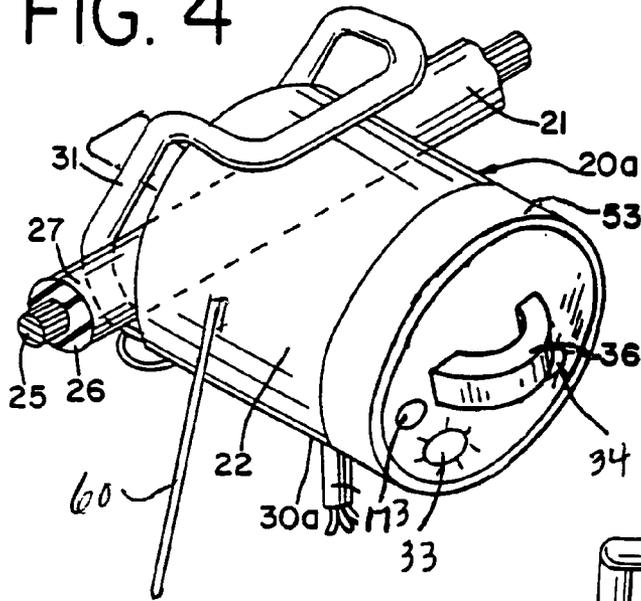


FIG. 5

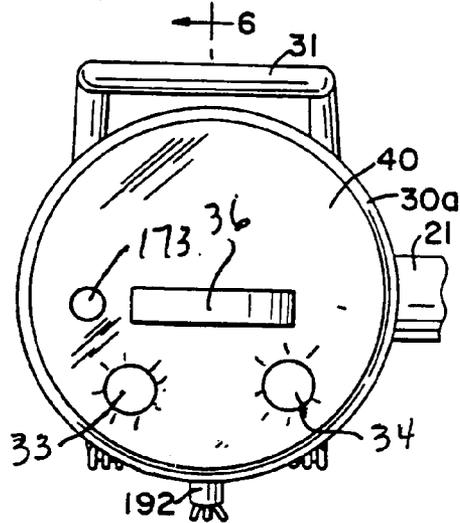


FIG. 6

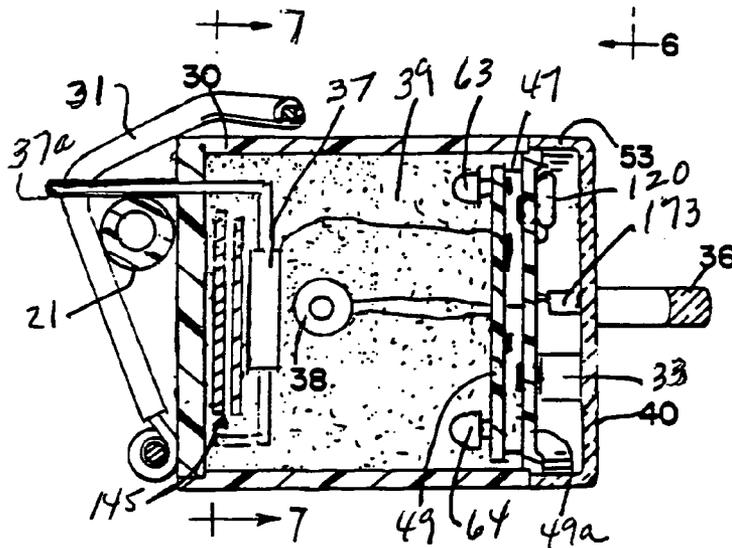


FIG. 7

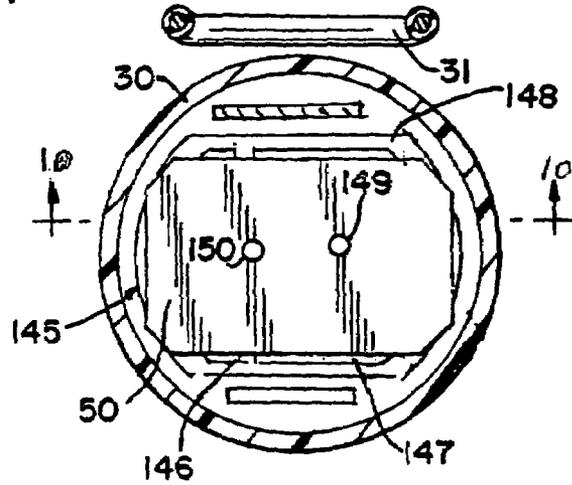


FIG. 8

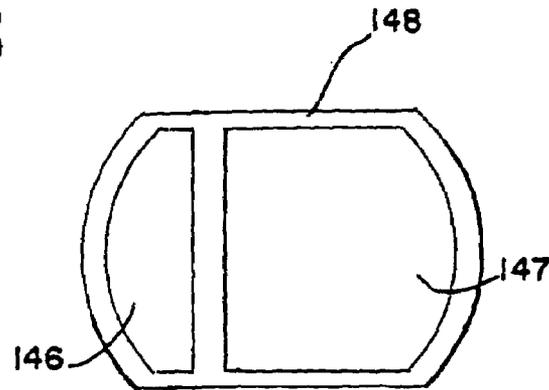


FIG. 9

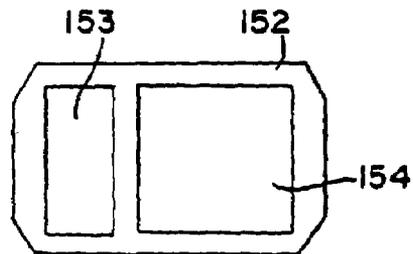


FIG. 10

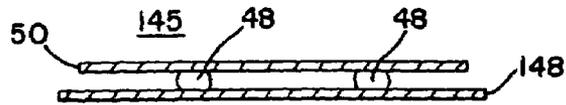


FIG. 13

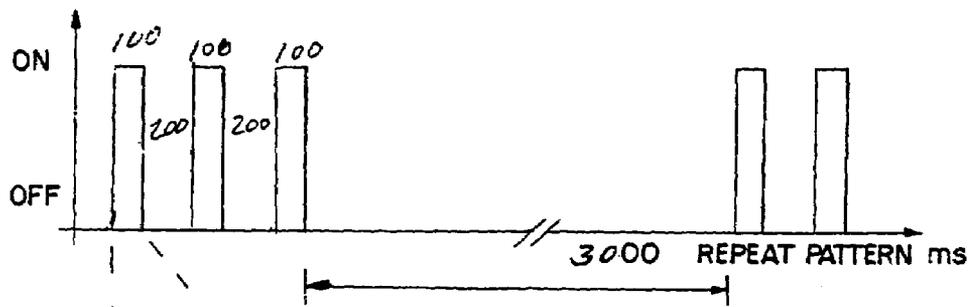
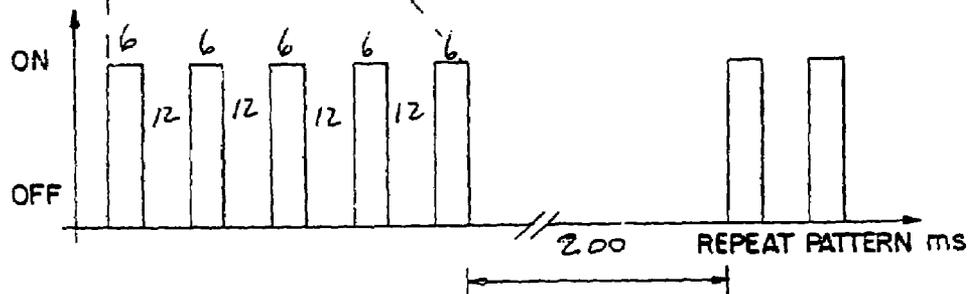


FIG. 14



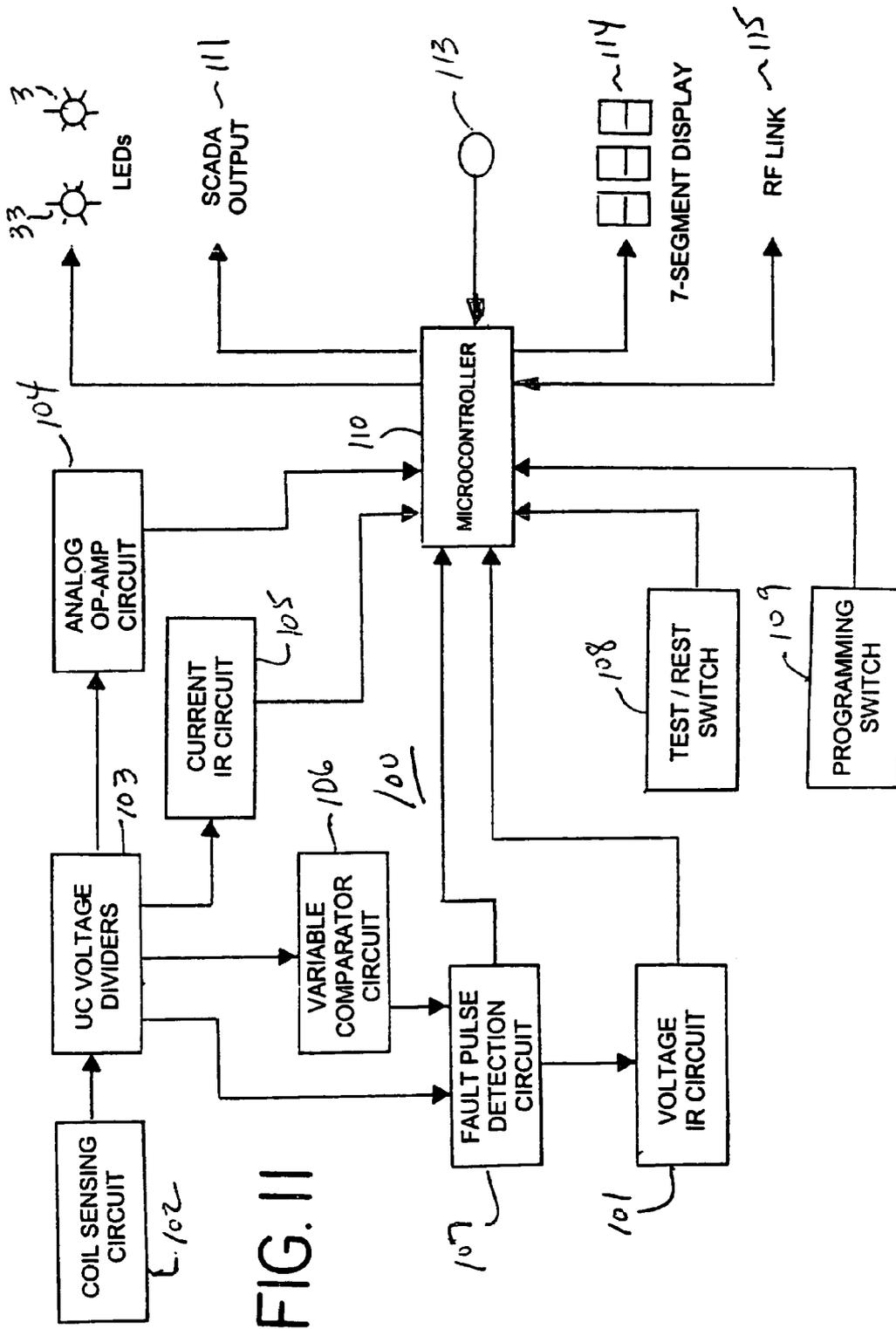
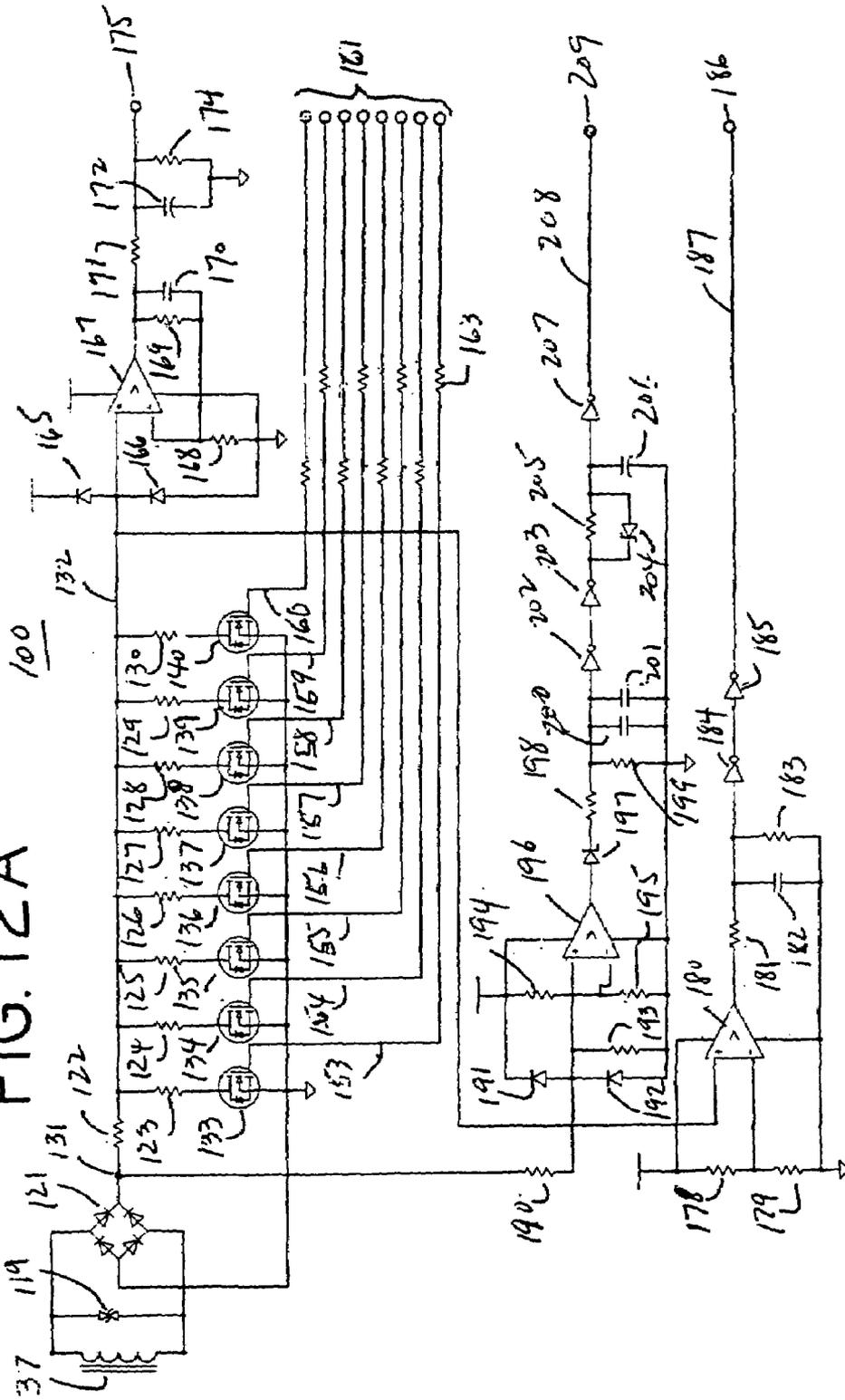


FIG. II

FIG. 12A



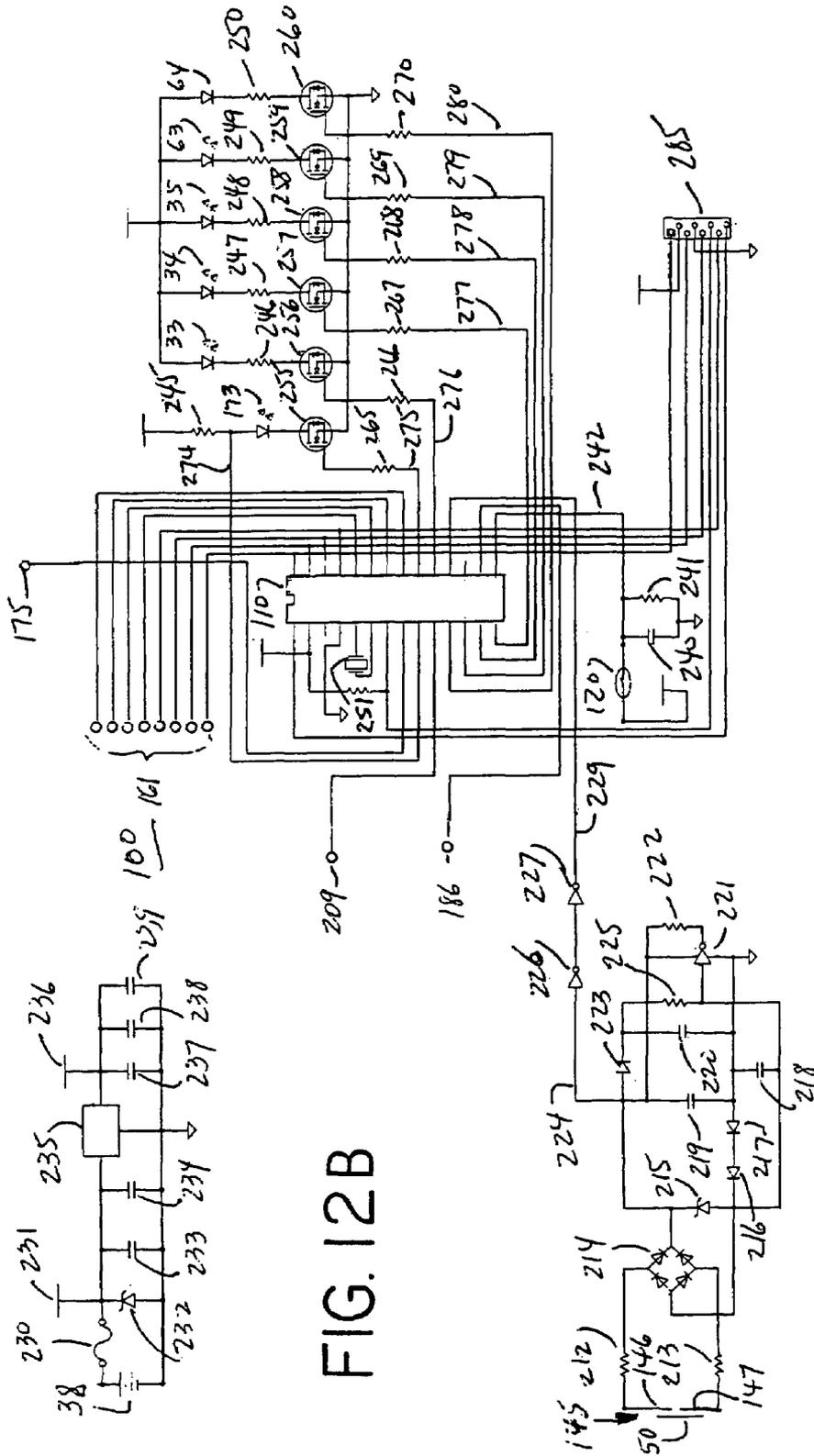


FIG. 12B

FIG. 15

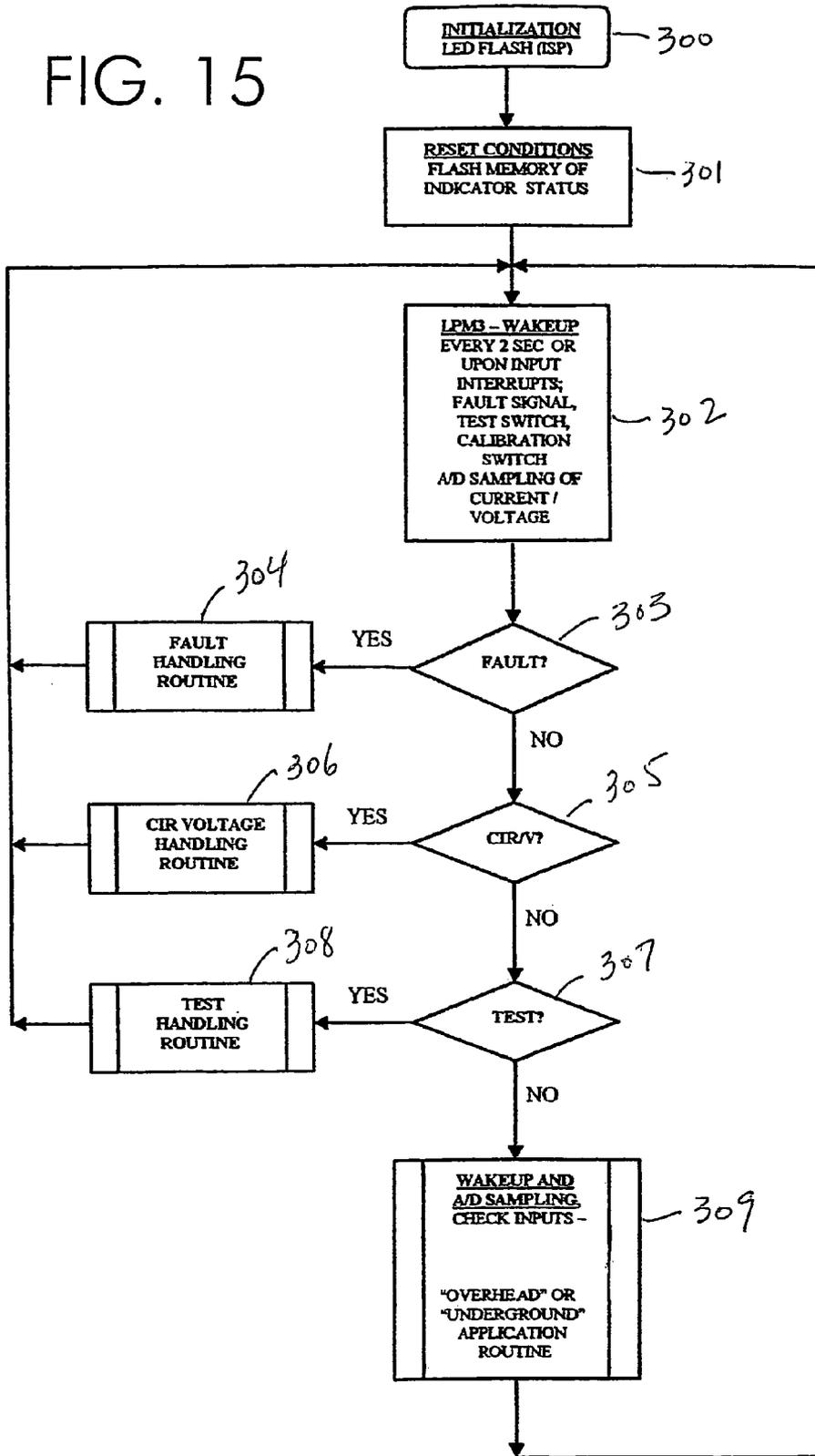


FIG. 16A

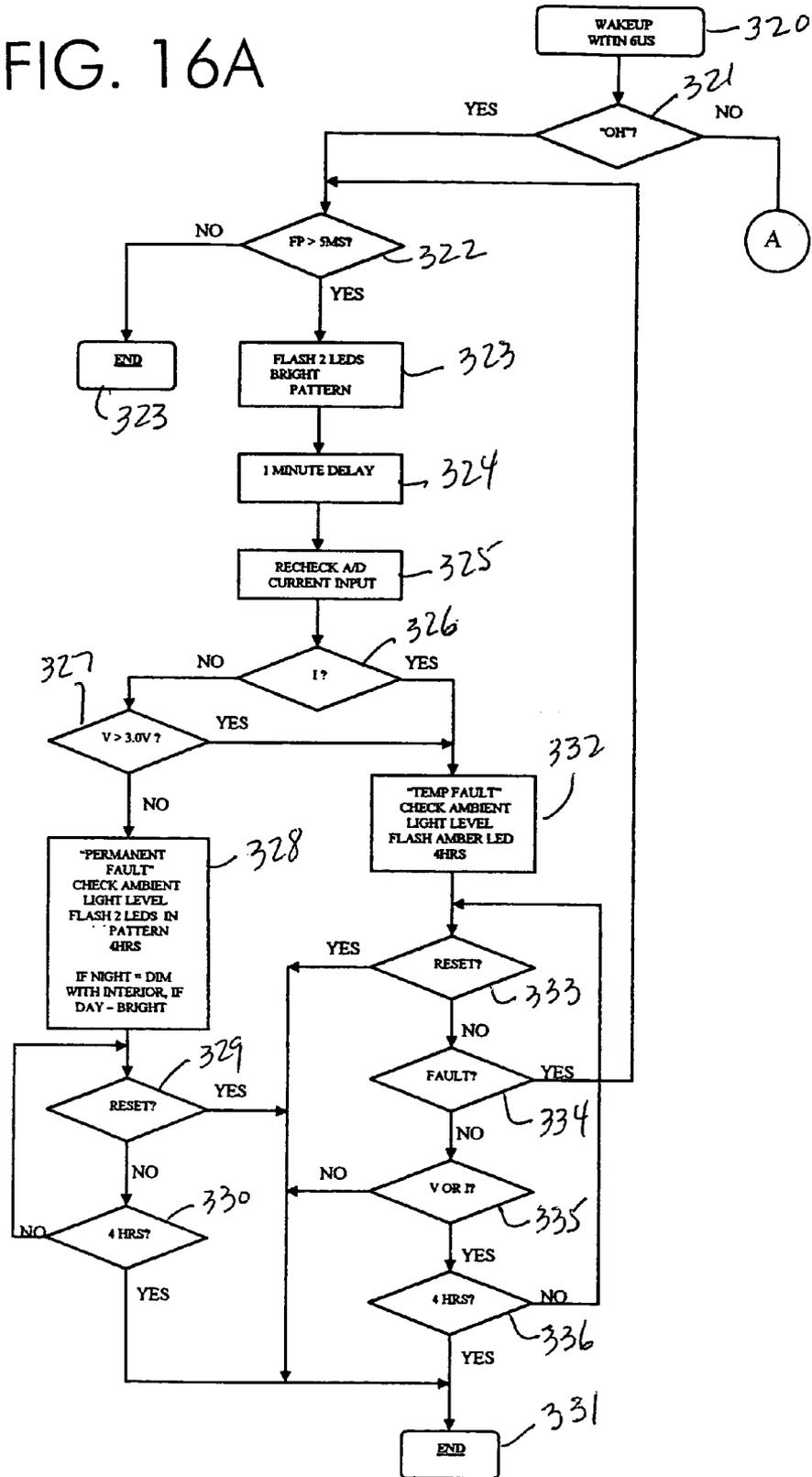


FIG. 16B

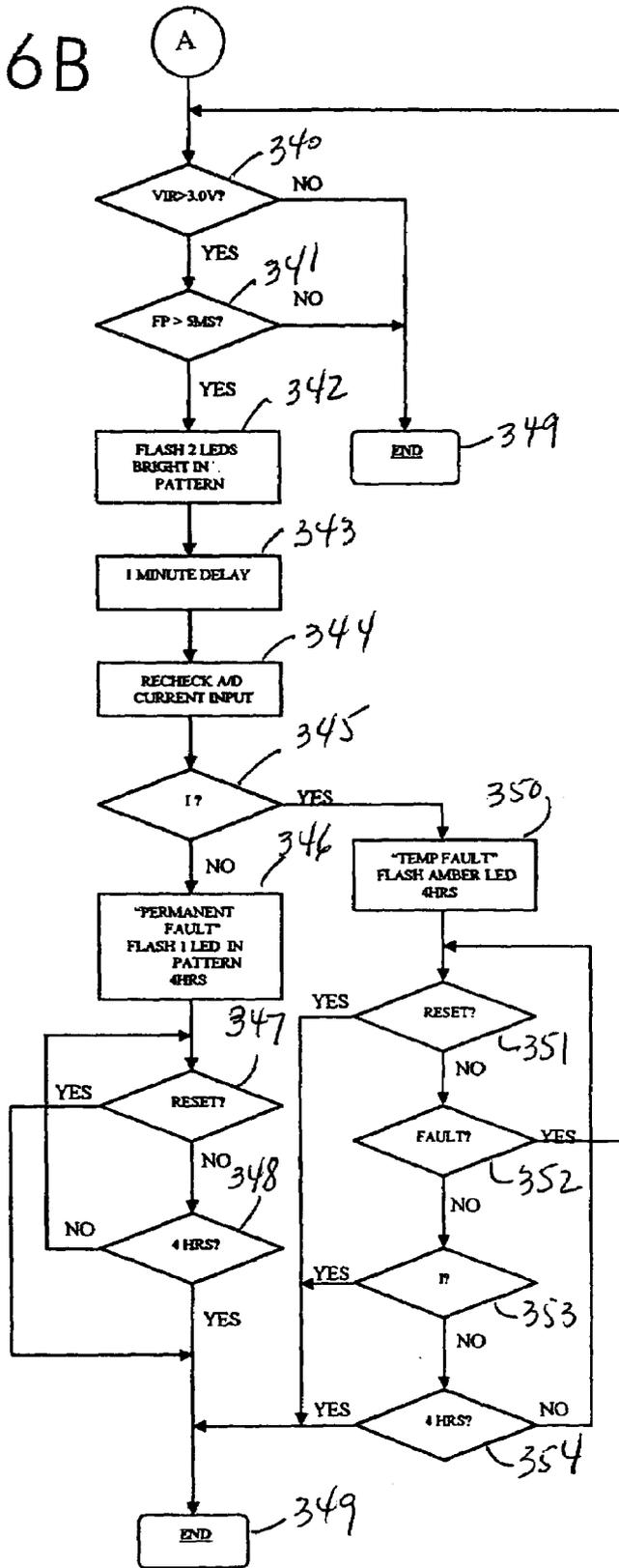


FIG. 17

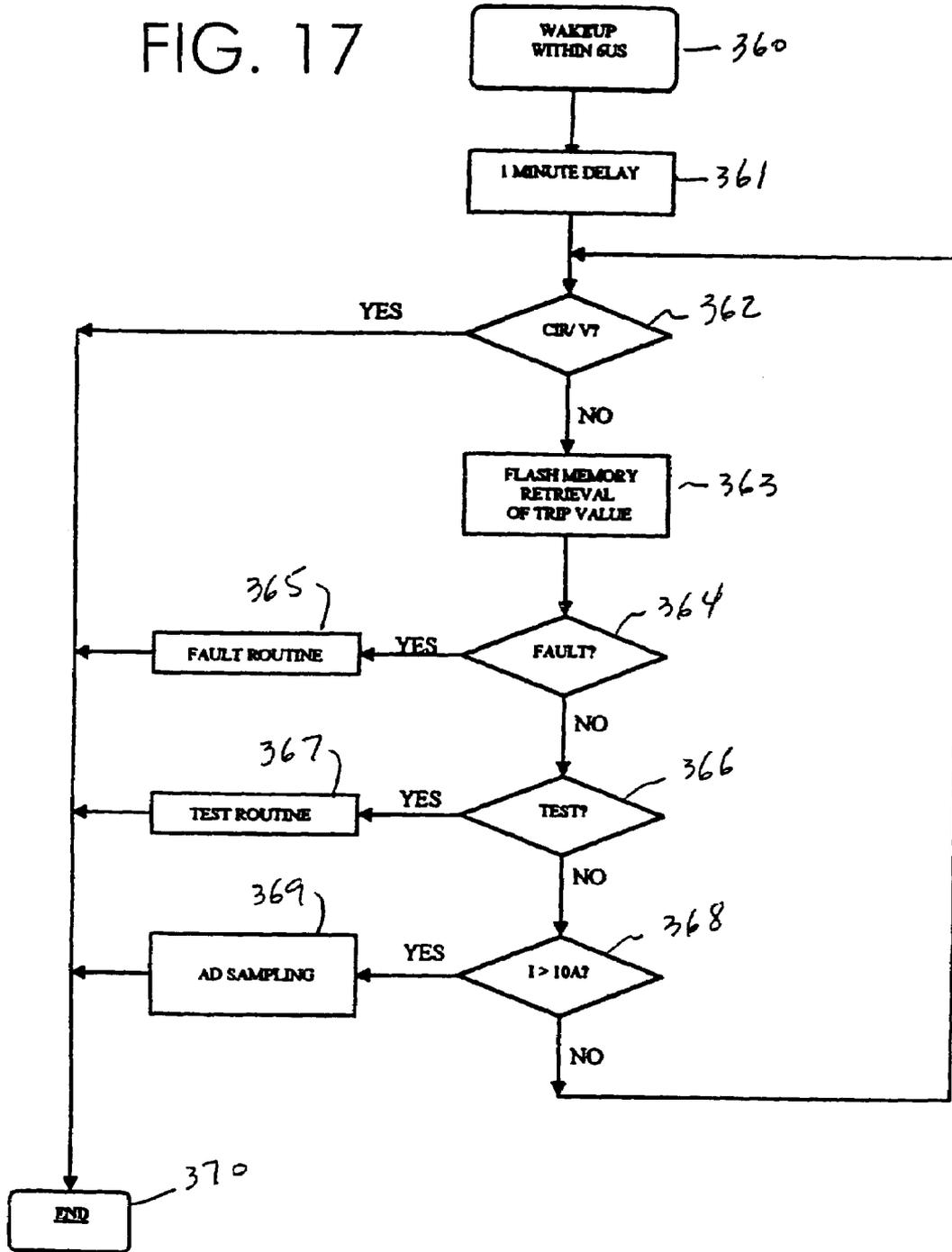


FIG. 18

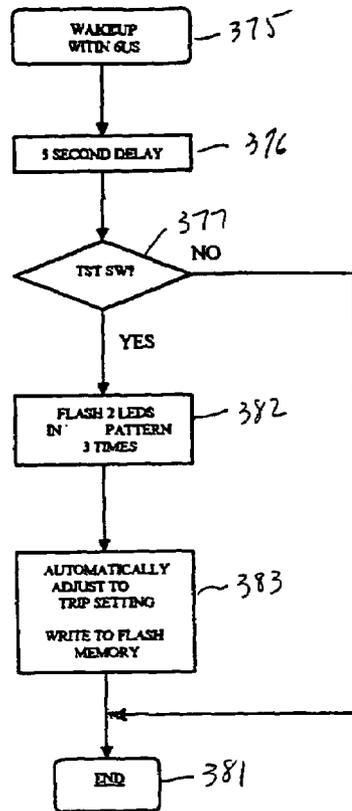


FIG. 19

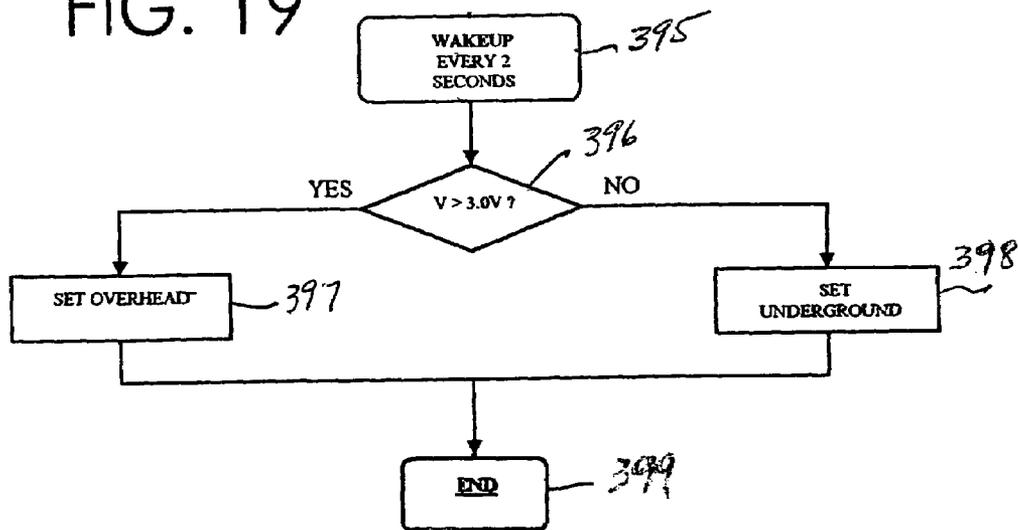


FIG. 21

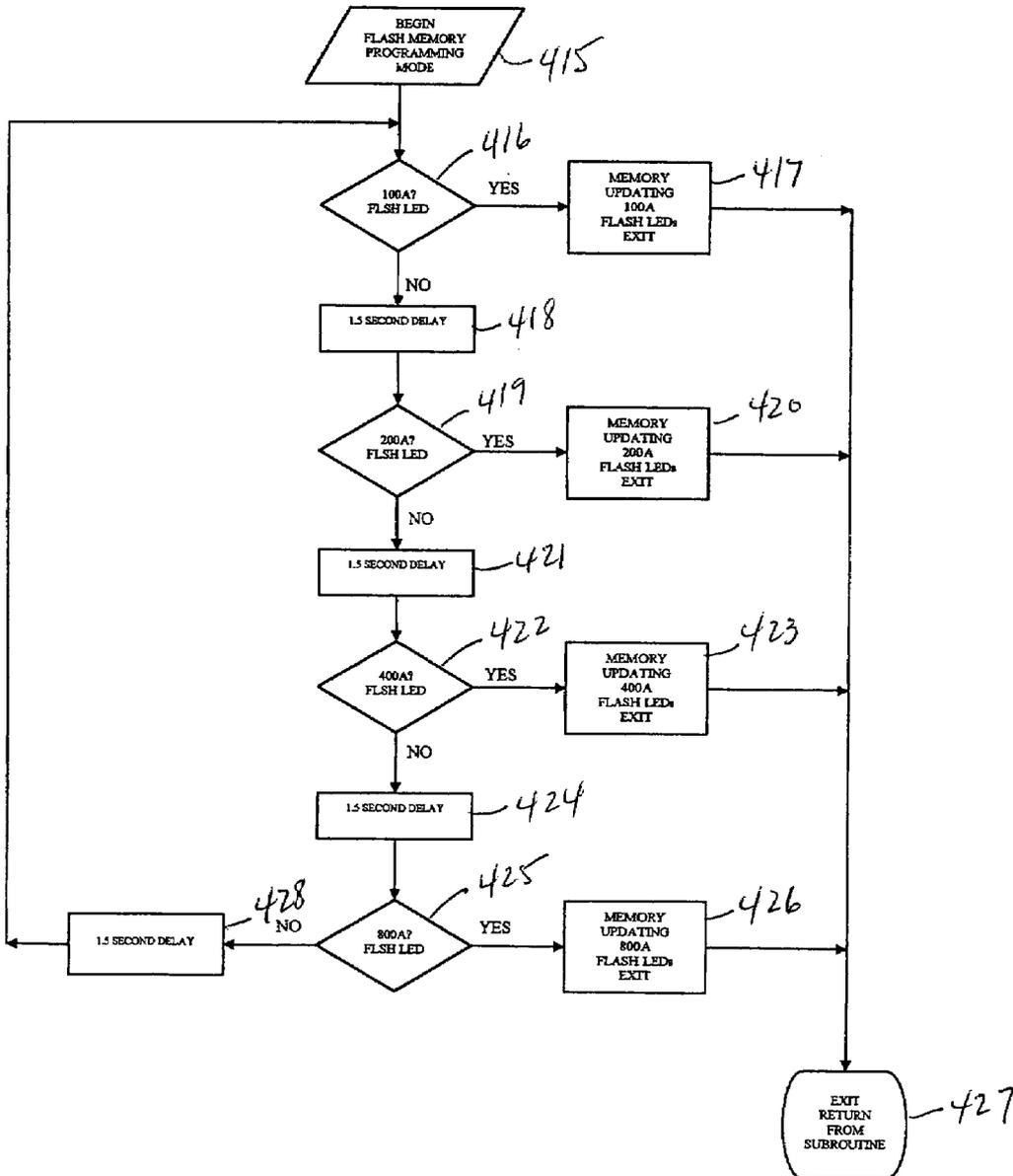
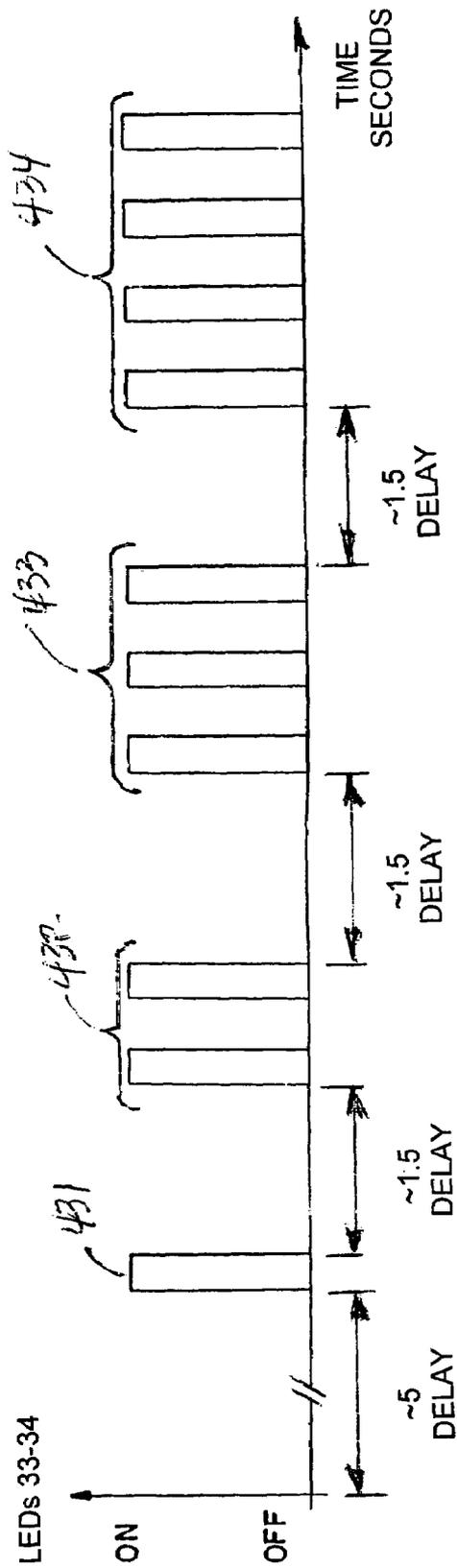


FIG. 22



**APPARATUS AND METHOD FOR
PROGRAMMABLE TRIP SETTINGS IN A
FAULTED CIRCUIT INDICATOR**

CROSS-REFERENCE TO RELATED
APPLICATIONS

This patent application is a non-provisional patent application of provisional patent application Fault Indicator with Field Programmable Trip, Ser. No. 60/519,106, filed on Nov. 12, 2003. This patent application is also a continuation-in-part patent application of the following/patent applications: Microprocessor Controlled Fault Indicator with Battery Conservation Mode, Ser. No. 10/280,322, filed on Oct. 25, 2002, now abandoned, and Ser. No. 60/339,412, filed on Oct. 26, 2001; Microprocessor Fault Indicator Having LED Fault Indication Circuit with Battery Conservation Mode, Ser. No. 10/280,219, filed on Oct. 25, 2002, now U.S. Pat. No. 6,734,662 and Ser. No. 60/337,631, filed on Oct. 26, 2001; Microprocessor Fault Indicator Having High Visibility LED Fault Indication, Ser. No. 10/280,141, filed on Oct. 25, 2002, now U.S. Pat. No. 7,053,601, and Ser. No. 60/339,256, filed on Oct. 26, 2001; Microprocessor Controlled Fault Indicator Having Inrush Restraint Circuit, Ser. No. 10/280,329, filed on Oct. 25, 2002, and Ser. No. 60/337,438, filed on Oct. 26, 2001; Microprocessor Controlled Directional Fault Indicator, Ser. No. 10/280,195, filed on Oct. 25, 2002, now abandoned, and Ser. No. 60/339,514, filed on Oct. 26, 2001; Microprocessor Controlled Fault Indicator with Circuit Overload Condition Detection, Ser. No. 10/280,328, filed on Oct. 25, 2002, now U.S. Pat. No. 6,822,576 and Ser. No. 60/337,632, filed on Oct. 26, 2001; Fault Indicator with Automatically Configured Trip Levels, Ser. No. 10/454,851, filed on Jun. 4, 2003, now U.S. Pat. No. 6,894,478; Fault Indicator with Permanent and Temporary Fault Indication, Ser. No. 10/454,850, filed on Jun. 4, 2003, now U.S. Pat. No. 7,023,691; Fault Indicator with Auto-Configuration for Overhead or Underground application Ser. No. 10/455,670, filed on Jun. 4, 2003, now U.S. Pat. No. 7,106,048 and Auto-Calibration of Multiple Trip Settings in a Fault Indicator, Ser. No. 10/454,847, filed on Jun. 4, 2003, now U.S. Pat. No. 6,949,921, all of which are incorporated herein by reference, and the rights of priority of which are all hereby claimed for this application.

BACKGROUND OF THE INVENTION

The present invention relates generally to current sensing devices for electrical systems, and more particularly to fault indicators for alternating current power systems that may be manually programmed to one of a plurality of trip settings.

Various types of self-powered fault indicators have been constructed for detecting electrical faults in power distribution systems, including clamp-on type fault indicators, which clamp directly over cables in the systems and derive their operating power from inductive and/or capacitive coupling to the monitored conductor; and test point type fault indicators, which are mounted over test points on cables or associated connectors of the systems and derive their operating power from capacitive coupling to the monitored conductor.

Some prior art fault indicators detect a fault by monitoring the rate of change of current in the monitored conductor over time, such as by using the current derivative, di/dt . For example, the rate of change of current may have to exceed 100 amperes (A) within 50 milliseconds (ms). However, if

a fault occurs with a slower current derivative, the fault may go undetected and no fault indication will occur.

Other prior art fault indicators may be either of the manually resetting type, wherein it is necessary that the indicators be physically reset, or of the self-resetting type, wherein the indicators are reset upon restoration of line current. Examples of such fault indicators are found in products manufactured by E.O. Schweitzer Manufacturing Company of Mundelein, Ill., and in U.S. Pat. Nos. 3,676,740, 3,906,477, 4,063,171, 4,234,847, 4,375,617, 4,438,403, 4,456,873, 4,458,198, 4,495,489, 4,974,329, 5,677,678, 6,016,105, 6,133,723 and 6,133,724.

Detection of fault currents in a monitored conductor by a prior art fault indicator is typically accomplished by magnetic switch means, such as by a configured magnetic reed switch, in close proximity to the conductor being monitored. Upon occurrence of an abnormally high fault-associated magnetic field around the conductor, the magnetic switch actuates a trip circuit that produces current flow in a trip winding to position an indicator flag visible from the exterior of the indicator to a trip or fault indicating position. Upon restoration of current in the conductor, a reset circuit is actuated to produce current flow in a reset winding to reposition the target indicator to a reset or non-fault indicating position, or the fault indicator may be manually reset.

Rather than a target indicator, some prior art fault indicators utilize light emitting diodes (LEDs) to display a fault condition. Whether of the target or LED display type, prior art fault indicators typically have a pre-set trip setting, such as 100 A, 200 A, 400 A, 800 A, 1200 A, or the like. This means that a variety of fault indicators must be manufactured, inventoried and sold to satisfy each specific load current application.

There is therefore a need for a fault indicator with multiple trip settings that can be easily manually programmed to a selected one of a plurality of different available trip levels.

There is a further need for such a fault indicator that is normally in an energy conservation mode and that periodically wakes up to monitor the load conditions on the monitored conductor, or is awakened when a fault condition occurs, when the fault indicator is reset after a timed reset period, or when a microcontroller in the fault detector otherwise receives an input or interrupt signal.

In certain other applications, the need arises for a fault indicator that will continue to display a prior fault condition for a predetermined amount of time, such as in the range of one hour to twenty-four hours, rather than self-resetting upon restoration of current in the conductor. Such timed reset fault indicators should be capable of self-resetting after termination of the predetermined time.

Some of these applications also require voltage in-rush restraint and/or current in-rush restraint to prevent false tripping due to voltage and/or current inrush, such as when a reclosing relay of a power distribution system closes to restore power.

Because of the compact construction and limited power available in self-powered fault indicators, it is preferable that the desired functions of the fault indicator be accomplished with minimal structure and with internal circuitry that has minimal current drain on a high capacity battery. The fault indicator must also provide highly reliable and extended operation over a number of years.

Accordingly, it is a general object of the present invention to provide a new and improved fault indicator that may be manually programmed to one of a plurality of available trip settings.

Another object of the present invention to provide a new and improved fault indicator that may be manually programmed or reprogrammed in the field after the fault indicator is installed on a conductor to one of a plurality of available trip settings.

A further object of the present invention is to provide a fault indicator that is capable of operating over a broad range of load currents, such as may be programmed from about 5 A to about 2500 A.

Yet another object of the present invention to provide a new and improved fault indicator that may be manually programmed or reprogrammed in the field by initiating a programming routine with a magnetic tool.

SUMMARY OF THE INVENTION

This invention is directed to a fault indicator for indicating the occurrence of a fault current in an electrical conductor. The fault indicator has a housing, a battery, a display for indicating that a fault in a monitored conductor has occurred, a current sensor for sensing the load current in the monitored conductor and for providing a load current signal that is related to the load current, and a microcontroller that receives the load current signal, that determines the load current in the monitored conductor, that may be manually programmed to one of a plurality of trip settings and that determines that a fault condition has occurred when the load current exceeds the trip setting. For example, the fault indicator may have selectable trip settings of 25 A, 50 A, 10 A, 200 A, 400 A, 600 A, 800 A, 1000 A, 1200 A and 2500 A, or any subset thereof.

If a test tool magnet is held up to the housing of the fault indicator for greater than about five seconds, the fault indicator will enter the programming mode. For example, an LED disposed on the face of the fault indicator may flash once to indicate a 100 A trip level, flash twice to indicate a 200 A trip level, flash three times to indicate a 400 A trip level and flash four times to indicate an 800 A trip level. Between each of the flashing indications of trip levels, there may be a predetermined time delay, such as about 1.5 seconds. The desired trip value is selected by removing the magnet from proximity to the housing while the desired trip level is flashing. Upon removal of the magnet, the LED will again flash the programmed trip level that was selected, thereby confirming the selected trip level. The selected trip level is then stored in a flash memory where it can be recalled as needed.

When a fault is detected, one or more LEDs disposed on the face of the fault indicator will begin to flash. At a predetermined time, such as about three minutes, the fault indicator again checks the electrical distribution system to see if voltage is restored on the monitored conductor. If not, the LEDs on the fault indicator will continue to flash for another predetermined time, such as up to 16 hours, or until voltage is restored on the monitored conductor.

Memory, such as flash memory, is preferably available for the microcontroller to store and to recall information, such as the field programmed trip setting, whether a fault is a permanent fault or a temporary fault, the time remaining before a timed reset will occur, the ambient lighting conditions, whether the fault indicator is configured for an overhead application or an underground application, and the like. Such memory may be available internally in the microcontroller or data processor.

The present invention is also directed to methods of manually programming a fault indicator to a selected one of a plurality of available trip settings. The steps of the method

may include sensing the load current in the monitored conductor with the current sensor, providing a load current signal from the current sensor that is related to the load current in the conductor; providing a plurality of selectable trip settings for the fault indicator; determining the load current in the conductor based upon the load current signal for the sensor and selecting one of the plurality of trip settings by initiating a programming routine. Additional steps may include storing the selected trip setting in a memory for recall by the data processor, displaying the trip level being programmed during running of the programming routine, manually initiating the programming routine by placement of a magnet in proximity to said fault indicator, terminating the programming routine at the desired trip setting by removal of the magnet in proximity to the fault indicator before the programming routine moves to the next trip setting, selecting the trip settings from a range of about 5 to about 1200 amperes and selecting the trip settings from the group consisting of 25, 50, 100, 200, 400, 600, 800, 1000 and 1200 amperes.

Further method steps may include flashing the display once to indicate when the programming routine is programming the fault indicator at a first trip setting, flashing the display twice to indicate when the programming routine is programming the fault indicator at a second trip setting, flashing the display three times to indicate when the programming routine is programming the fault indicator at a third trip setting and flashing the display four times to indicate when the programming routine is programming the fault indicator at a fourth trip setting. Still further method steps may include causing a magnetic switch to change state from open to closed or from closed to open in response to the magnet being placed in proximity to the fault indicator, sensing the change in state of the magnetic switch from open to closed or from closed to open at the data processor and initiating the programming routine to program the fault indicator to one of said plurality of trip settings.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The invention, together with the further objects and advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings, in the several figures in which like reference numerals identify like elements, and in which:

FIG. 1 is a perspective view of an electric field powered clamp-on fault indicator with provision for external battery replacement that is constructed in accordance with the present invention and that may be installed on a cable within a power distribution system.

FIG. 2 is a front view of the fault indicator of FIG. 1 showing illuminated LEDs to indicate the occurrence of a fault.

FIG. 3 is a cross-sectional view of the fault indicator of FIGS. 1 and 2 taken along the sectional line 3-3 of FIG. 2. FIG. 4 is a perspective view of an alternate embodiment of the electric field powered fault indicator shown in FIGS. 1-3, with an internal non-replaceable battery, constructed in accordance with the present invention and installed on a cable within a power distribution system.

FIG. 5 is a front view of the fault indicator of FIG. 4 showing illuminated LEDs to indicate the occurrence of a fault.

FIG. 6 is a cross-sectional view of the fault indicator of FIGS. 4 and 5 taken along the section line 6-6 of FIG. 5.

FIG. 7 is a cross-sectional view of the fault indicator of FIGS. 4-6 taken along the section line 7-7 of FIG. 6 to better illustrate an electrostatic pickup for deriving power from the electromagnetic field around the conductor of the power distribution system, and to supply operating power to portions of the electronic circuitry in the fault indicators shown in FIGS. 1-6.

FIG. 8 is a plan view of a first embodiment of an electrostatic plate for the electrostatic pickup shown in FIG. 7.

FIG. 9 is a plan view of a second embodiment of an electrostatic plate for the electrostatic pickup shown in FIG. 7.

FIG. 10 is a cross-sectional view of the electrostatic pickup illustrated in FIG. 7 taken along section line 10-10.

FIG. 11 is a block diagram of the electronic circuitry used in the fault indicators of FIGS. 1-6 showing the functions and interrelationships of the various circuit portions.

FIGS. 12A and 12B together constitute an electrical schematic diagram of the electronic circuitry for the fault indicators shown in FIGS. 1-6.

FIG. 13 is a timing diagram showing a preferred illumination pattern for the LEDs used in the fault indicators of FIGS. 1-6.

FIG. 14 is a timing diagram showing a preferred illumination pattern for applying lower power to the LEDs used in the fault indicators of FIGS. 1-6 under night time conditions.

FIG. 15 is a flow chart illustrating typical steps that may be employed by a microcontroller during the various operational modes of the fault indicators illustrated in FIGS. 1-6.

FIGS. 16A and 16B are flow charts illustrating typical steps that may be employed by a microcontroller during a fault handling routine shown in one of the blocks of FIG. 15.

FIG. 17 is a flow chart illustrating typical steps that may be employed by a microcontroller during current and voltage inrush routines shown in another block of FIG. 15.

FIG. 18 is a flow chart illustrating typical steps that may be employed by a microcontroller during test handling routines shown in another block of FIG. 15.

FIG. 19 is a flow chart illustrating typical steps that may be employed by a microcontroller during wakeup and overhead/underground routines shown in another block of FIG. 15.

FIG. 20 is a flow chart illustrating typical steps that may be employed by a microcontroller during the various operational modes of the fault indicators illustrated in FIGS. 1-6, in accordance with the present invention.

FIG. 21 is a flow chart illustrating typical steps that may be employed by a microcontroller during a programming mode routine shown in a block of FIG. 19, also in accordance with the present invention.

FIG. 22 is a timing diagram illustrating a preferred illumination pattern in accordance with the present invention for activating the LEDs used in the fault indicators of FIGS. 1-6 while programming the fault indicator to one of a plurality of available trip settings.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the Figures, and particularly to FIG. 1, a clamp-on timed reset fault indicator, generally designated 20, is constructed in accordance with the invention. Fault indicator 20 indicates fault currents in an electrical feeder or distribution cable, generally designated 21, and includes a circuit module, generally designated 22. Cable 21 may be part of an overhead electrical distribution system or of an

underground distribution system, such as where the cable comes up from the ground at a pad-mounted transformer. In accordance with conventional practice, circuit module 22 is attached to the outer surface of the cable 21, which may include a central conductor 25, a concentric insulating layer 26 and an electrically grounded rubber outer sheath 27.

Circuit module 22 includes a housing 30 (FIG. 2) that contains electronic circuitry for sensing and responding to fault currents in cable 21. A current transformer 37 is located within housing 30 and has a pole piece 37a that extends through housing 30 in an orientation that is generally perpendicular to the rear face of housing 30. The exterior portion of pole piece 37a may be coated with an insulative material or may have an insulating sleeve disposed thereon.

A clamp assembly 31 attaches the module to a monitored conductor, such as cable 21, and holds cable 21 in close proximity to the pole piece 37a of current transformer 37. Clamp assembly 31 is designed to accommodate a range of cables 21 having different diameters. Current transformer 37 senses the load current in conductor 21 and provides a signal representative of the load current to electronic circuitry 100, which is discussed below. An electrostatic sensor 145 is disposed between current transformer 37 and the rear wall of housing 30. Sensor 145 senses the electromagnetic field about conductor 21 and likewise provides a signal representative of the electromagnetic field to electronic circuitry 100. Sensor 145 is also discussed below, including details on the construction and operation of the electrostatic sensor.

An eye 36 on an end cap 53 of the housing may be provided to allow use of a conventional hotstick during installation or removal of fault indicator 20 about cable 21. When installed on an overhead cable, fault indicator 21 normally hangs downwardly such that a face 40 containing the status indicators, such as LEDs 33-34, are easily viewed from the ground by service personnel or the like.

Housing 30 and end cap 53 may be formed from any suitable material, such as plastic. End cap 53 forms part of the housing 30, and may be sonically welded to housing 30 to seal the interior of fault indicator 20 against contamination. A battery holder 28 within housing 30 includes a removable end cap 29 which provides access to a cylindrical battery compartment within which a battery 38 (FIG. 3) is contained. In this example, battery 38 may be one or more type AA lithium thionyl chloride cells that have about 2.4 ampere-hours of capacity and that are commercially available from Tadiran, Ltd. of Israel.

Circuit module 22 also includes status indicators, such as two LEDs 33-34, to indicate whether a fault has occurred on cable 21. In operation, during normal current flow through conductor 21, LEDs 33-34 are normally off and not illuminated. Upon occurrence of a fault in a monitored conductor, LEDs 33 and 34 are illuminated by electronic circuitry, which is discussed in further detail below, to indicate that a permanent fault has occurred. For best viewing from different angles of view, LEDs 33-34 are nearly flush with the exterior surface of end cap 53. If desired, LEDs 33-34 may project slightly above the top surface 40 of the end cap 53, or end cap 53 may be provided with convex lenses (not shown) to provide illumination in about a 180° field of view for better viewing by service personnel. LEDs 33-34 may be selected from any color commercially available. For example, LEDs 33 and 34 may be red for indicating a permanent fault. If one of LEDs 33 or 34 is used for indicating a temporary fault, it may be selected as a different color than red, such as yellow. End cap 53 is preferably of a contrasting color to LEDs 33-34, such as dark blue, for better visibility of the LEDs.

A light sensor 173 may be disposed on the face 40 of fault indicator 20 to sense ambient light levels. As further discussed below, light sensor 173 may influence the intensity of light provided by LEDs 33-34 under differing ambient light conditions. With reference to FIG. 3, a pair of circuit boards 49 and 49a are disposed in the housing 30 near the face end thereof. These circuit boards contain most of the electronic circuitry 100, which is presented in greater detail below. The circuit boards 49 and 49a are spaced apart with most of the circuitry disposed between the two circuit boards 49, 49a. A plurality of ground pins 47 disposed about the periphery of the circuit boards interconnect the ground planes in the circuit boards and, in combination with the circuit boards, provide a simulated Faraday cage to provide the circuitry with electromagnetic isolation to stray electromagnetic disturbances or the like. Circuit board 49a also supports LEDs 33-34, ambient light sensor 173, a magnetic reset switch 120 and various other components.

A pigtail 192 may provide signals relating to the operational status of fault indicator 20, such as to a remote location, for remotely monitoring the electrical distribution system or for automation purposes.

Additional LEDs 63-64 may be disposed internally in housing 30, such as in the potting compound 39 that encases most of the electronic circuitry. It may be desirable to use two interior LEDs 63-64 because certain other internal components, such as battery 38, may block a substantial portion of the illumination at certain viewing angles from a single LED. Additional LEDs 63-64 become illuminated during a fault condition when the light sensor 173 senses a low ambient lighting level, such as at nighttime. The objective is to make housing 30 glow or flash in the dark after a sensed fault condition for better visibility, including from all directions. To this end, potting compound 39 is preferably clear and housing 30 is preferably formed from translucent plastic. Of course, other combinations of materials may be selected to achieve similar results, such as translucent potting compound 39 with a clear or translucent housing 30. When interior LEDs 63-64 are illuminated after sensing a fault condition at reduced ambient light levels, some of LEDs 33-34 are also preferably illuminated to indicate the fault condition from the face 40 of fault indicator 20, depending upon whether the detected fault condition is determined to be permanent or temporary.

FIGS. 4-6 illustrate a fault indicator 20a, which is an alternate embodiment of fault indicator 20 shown in FIGS. 1-3. A primary difference between fault indicators 20 and 20a is that fault indicator 20a in FIGS. 4-6 is not equipped with a battery that is externally replaceable. Thus, housing 30a does not have a battery compartment 28 with a removable cap 29. Instead, a permanent and high-capacity battery 38a may be potted in potting compound 39 at the time of manufacture. Since fault indicator 20a consumes battery current mostly during a fault condition, as will be understood more fully below, permanent battery 38a can be expected to last for the lifetime of fault indicator 20a, such as for 10 or more years. Battery 38a is preferably a lithium thionyl chloride battery, such as type TL-593-S manufactured by Tadiran, Ltd. of Israel, which provides a constant 3.6 volt output to depletion. This battery is of the standard C size with a nominal capacity rating of 8.5 ampere-hours. Optionally, battery 38a may be of the standard D size with a nominal capacity of 19 ampere-hours.

Fault indicators 20-20a (collectively fault indicator 20) all preferably have a timed reset to reset some hours after a fault occurs. Thus, fault indicator 20 continues to display the fault by periodically illuminating some of LEDs 33-34, and LEDs

63-64 at nighttime, if implemented, after power is restored in cable 21. This enables a lineman or other service personnel to easily trace the fault by following the illuminated fault indicators. The point of the fault may then be located and repaired, or the cable 21 may be replaced. As will be understood hereinafter, the length of the timed reset may be in the range of 1 to 24 or more hours, and is preferably about 16 hours. Sixteen hours normally provides sufficient time for a lineman or repair crew to review the tripped fault indicators to determine the part of the distribution system associated with the fault.

Rather than waiting for the predetermined reset time to elapse, fault indicator 20 may be manually reset at any time. To this end, a reset magnetic reed switch 120 is disposed in the housings 30-30a. Magnetic reed switch 120 may be manually closed with a permanent magnet tool 60 (FIG. 4) in a manner known to the art.

Turning now to FIG. 11, the electronic circuitry, generally designated 100, for fault indicator 20 is shown in block diagram form. A voltage inrush restraint circuit 101 includes a voltage sensor which may take the form of an electrostatic sensor 145 shown in FIGS. 7-10. Electrostatic sensor 145 may include a generally rectangular and flat metallic plate 50 overlying an insulating substrate 148 with a pair of metal electrodes 146 and 147 thereon (FIG. 8). For example, metallic plate 50 may be spaced apart from substrate 148 by small insulating spacers 149 (FIG. 10) so that electrostatic coupling exists between metal plate 50 and electrodes 146 and 147. For example, the distance between plate 50 and substrate 148 may be about 2 to 5 mm.

Substrate 148 with the electrodes 146 and 147 thereon may be fabricated by any suitable means, including printed circuit board techniques, deposition of metal on a ceramic substrate or by physically adhering metal foil onto a phenolic base. For example, the electrodes 146 and 147 may be a copper-nickel alloy foil about 10 to 12 thousandths of an inch (0.25 to 0.30 mm) thick. Metallic plate 50 is preferably provided with one or more apertures, such as 149 and 150 for good flow of a potting compound in and about the electrostatic sensor. For example, a urethane-based potting compound may be used, such as that commercially available under the BIWAX brand from the Biwax Corporation of Des Plaines, Ill. BIWAX is a registered trademark owned by the Biwax Corporation.

With reference to FIGS. 3 and 6, the interior of housing 30 or 30a, which houses a magnetic reed switch 120, electrostatic sensor 145, current transformer 37, battery 38 or 38a, interior LEDs 63 and 64 and circuit boards 49 and 49a, may be potted with the potting compound, or any desired portion thereof.

As seen in FIG. 8, electrodes 146 and 147 are preferably of different area such that differences in charge on electrodes 146 and 147 will develop a differential electrical signal between electrodes 146 and 147. For example, the area of electrode 146 may be about 15 to 75 percent of the area of electrode 147, and is preferably about 25 to 50 percent of the area of electrode 147.

Illustrated in FIG. 9 is an alternative embodiment of the substrate 148 in FIG. 8. In this embodiment, substrate 152 of insulating material may be of the same approximate rectangular configuration as metal plate 50. Generally rectangular metallic electrodes 153 and 154 are deposited on or adhered to the substrate 152, in a manner similar to substrate 148. Electrode 154 is of greater area than electrode 153 for the same reasons and same purpose as electrodes 146 and 146 in FIG. 8. For example, electrode 153 may be about 15

to 75 percent of the area of electrode **154**, and is preferably about 25 to 50 percent of the area of electrode **154**.

Electrostatic sensor **145** in FIGS. 7-10 provides excellent immunity to stray electrical fields from adjacent electrical conductors in an electrical distribution system. For example, when the electrostatic pick up portions are physically separated, such as the plate 50 and the conductive band 51 shown in FIG. 3 of U.S. Pat. No. 6,016,105, the separate electrostatic pick up components may cause false triggering upon voltage in-rush in an adjacent conductor, instead of in the monitored conductor. Electrostatic sensor **145** of the present invention substantially avoids these unwanted stray effects and false triggering with the above-described dual electrodes of unequal area disposed on a single substrate **148** or **152**.

Returning now to FIG. 11, a coil sensing circuit **102**, which includes current transformer **37**, senses the load current in monitored conductor **21** including any fault currents. One of a plurality of voltage dividers **103** is selected by microcontroller **110** that corresponds to the selected trip setting. An analog operational amplifier circuit **104** monitors the voltage at the selected voltage divider **103**, and provides an output to microcontroller **110**. A current inrush restraint circuit **105** monitors any current inrush condition that might cause a false fault detection and provides a logic input signal to microcontroller **110**. A variable comparator circuit **106** and a fault pulse detection circuit **107** monitor the voltage dividers **103**. Fault pulse detection circuit **107** provides an input signal to microcontroller **110**. A voltage inrush circuit **101** also received an input signal from fault pulse detection circuit **107** and provides an input to microcontroller **110**. A test/reset switch **108** initiates a test routine in microcontroller **110**, or sends a reset signal to the microcontroller. A programming switch **109** is utilized during programming of the microcontroller.

In response to various circuit conditions, microcontroller can activate LEDs **33-34** to indicate that a fault has occurred, or for selection of the desired trip level for fault indicator **20** as described in further detail below. It can optionally provide a SCADA output signal **111**, such as at the pigtail **192**. Microcontroller **110** may optionally display information on a seven-segment display **114**, such as the amount of elapsed time since a fault occurred. Display **114** may be disposed on the face of fault indicator **20**. The microcontroller may also be optionally provided with a radio frequency (RF) link **115** to report status information to a data or communication system at a remote location, such as a system for monitoring the electrical distribution system that employs a plurality of fault indicators.

The electronic circuitry **100** for fault indicator **20** is shown in greater detail in the schematic diagram contained in FIGS. 12A-12B. Most of circuitry **100** will typically be located on circuit boards **49** and **49a** in housing **30** or **30a** (FIG. 3 or 6). The coil sensing circuit **102** includes current transformer **37**, a peak limiting device **119** and a full-wave diode rectification bridge **121**. Current transformer **37** may have, for example about 7000 windings on the core **37a**, and be able to detect a range of load current in monitored conductor **21** from about 5 A to about 1700 A. The output of current transformer **37**, after rectification by bridge **121**, is provided at node **131**.

The microcontroller voltage dividers **103** include resistors **122-130**, and a plurality of semiconductor switches, such as FETs **133-140**. The gate terminals of FETs **133-140** are connected by lines **153-160**, respectively, via a plurality of terminals **161** to corresponding terminals **161** in FIG. 12B to separate output terminals of microcontroller **110**. Each of lines **153-160** may be provided with a series resistor, such

resistor **163** in line **153**. Microcontroller **110** can configure the fault indicator for one of a plurality of current trip settings by rendering one of FETs **133-140** conductive by supplying an appropriate bias signal to the gate of one of the FETs. It will be appreciated that, depending upon which FET **133-140** is conductive, one of resistors **123-130** will be in series with resistor **122** to ground thereby dividing the voltage from the coil sensing circuit **102** at node **131** by the ratio of the resistors **122** and the selected one of resistors **123-130** to provide a voltage divided reference signal on line **132**. In effect, resistors **122** and the selected one of resistors **123-130** provide a current load on current transformer **37** to ground.

Resistors **122** and **123-130** are selected such that the reference voltage on line **132** provides a plurality of different current trip settings for the fault indicators **20-20a**. For example, rendering FET **133** conductive will configure the fault indicator for a 50 A trip setting. Likewise, FET **134** activates a 100 A trip setting, FET **135** activates a 200 A trip setting, FET **136** activates a 400 A trip setting, FET **137** activates a 600 A trip setting, FET **138** activates an 800 A trip setting, FET **139** activates a 1000 A trip setting and FET **140** activates a 1200 A trip setting. Of course, different trip settings, or fewer or more trip settings, could be associated with some or all of FETs **133-140**, if so desired.

Microcontroller **110** may be programmed to initially set the trip setting to a default setting of 200 A by activating FET **135**. Thereafter, the trip setting may be adjusted upward or downward to any other desired available trip level by manually initiated programming, which may be accomplished in the field after the fault indicator is installed on a monitored line, as further presented below. It will be appreciated that the voltage dividers **103** may be implemented in other forms, such as with a digital potentiometer. Additional voltage dividers may be implemented for additional trip settings, such as for 25 A and 2500 A.

The fault pulse detection circuitry **107** includes op amp **180**, resistors **178-179**, **181** and **183**, capacitor **182** and inverters **184-185**. Op amp **180** monitors the potential on line **132** at its non-inverting input. Its inverting input is supplied with a reference voltage, such as about 3.1 volts, by the voltage dividing resistors **178-179**. Thus, the output of op amp **180** will be near zero until the potential on line **132** rises above 3.1 volts, such as in response to a current fault in monitored conductor **21**. Resistors **181** and **183** and capacitor **182** provide filtering of any noise signals, or the like. Inverters **184-185** drive line **187**, which is connected to an input terminal of microcontroller **110** through terminal **186**. Thus, when a high potential appears on line **132**, the output of op amp **180** goes high and line **187** to microcontroller **110** switches to a logic high level. Microcontroller **110** will interpret the logic high signal to indicate that a current fault has occurred on monitored conductor **21**.

The basic functions of the voltage inrush restraint circuit **101** are to determine whether there is a voltage in conductor **21**, such as by sensing the collapse of the electromagnetic field about conductor **21** when the voltage falls during a fault or when a reclosing relay otherwise opens, and to inhibit activation of the display **40** to the fault indicating position when power is restored to the electrical distribution system. The basic functions of the current inrush restraint circuit **105** are similar, except that the current inrush restraint monitors the current in conductor **21** by receiving the rectified signal from current transformer **37**. In overhead applications, either voltage or current inrush restraint, or both, may be used. In underground applications, current inrush restraint is used. Of course, when power is restored, as by closing of the reclos-

ing relay, there is likely to be a subsequent current inrush or surge in conductor 21 because of the preexisting load on conductor 21. It is therefore desirable for the fault indicator 20 to avoid interpreting this current inrush as a fault condition on conductor 21.

It is also desirable to have the fault indicator 20 avoid falsely interpreting noise, arcing, transients, or the like, on conductor 21 as a fault. To this end, fault indicator 20 preferably has a delayed trip response time. Typically, in overhead applications, the delayed trip response time may be in the range of about 1 to 50 ms and typically about 24 ms. In underground applications, the delayed trip response time may be in the range of about 1 to 24 ms and typically about 1 ms.

The current inrush restraint circuit 105 includes op amp 196, resistors 190, 194-195, 198-199 and 205, diodes 191-192, Zener diodes 197 and 204, capacitors 200-201 and 206, and inverters 202-203 and 207. Op amp 196 monitors the output of the current sensing circuitry 102 at node 131 via resistor 190 connected to its non-inverting input. Resistors 190 and 193 divide the signal at node 131. The inverting input of op amp 196 is biased at a small reference potential by voltage dividing resistors 194 and 195. Normally, the signal at the non-inverting input of op amp 196 will exceed the signal at the inverting input and the output at Zener diode 197 will be at a logic high level, which forward biases Zener diode 197 to render it conductive. Resistor 198 is small in resistive value to resistor 199 so that a high signal also appears at the input of inverter 202. Capacitors 200-201 filter noise, or the like. Inverters 202-203 provide a logic high level to resistor 205 and Zener diode 204, which begins to charge up capacitor 206. Preferably, capacitor 206 is an electrolytic capacitor of a large capacitive value. As capacitor 206 is charged, inverter 207 will supply a logic low level on line 208 to terminal 209 to an input terminal of microcontroller 110. If power is lost on conductor 21 for a short time and then restored, capacitor 206 will still be charged because of its high impedance discharge paths. Thus capacitor 206 will cause inverter 207 to continue supplying a low logic level to microcontroller 110, thus inhibiting microcontroller 110 from misinterpreting a voltage inrush upon restoration of power to conductor 21 as a fault current condition.

With reference to FIG. 12B, the voltage inrush circuit 101 includes electrostatic sensor 145, resistors 212-213, 222 and 225, full-wave diode rectification bridge 214, Zener diode 215, diodes 216-217 and 223, capacitors 218-220, and inverters 221 and 226-227.

Electrostatic sensor 145 is shown consisting of a metallic plate 50, a smaller electrode 146 and a larger electrode 147. Each of electrodes 146 and 147 is connected through a current limiting resistor 212 and 213, respectively, to a full-wave diode rectification bridge 214 to supply a DC voltage to the voltage inrush restraint circuitry. A Zener diode 215 may be selected to limit the voltage from diode bridge 214 to approximately 5 volts. A capacitor 219 quickly charges up to the input voltage. Another capacitor 220 also quickly charges up to near the input voltage through a diode 223. However, if line voltage is temporarily lost, diode 223 will prevent rapid discharge of capacitor 220 except through the slower discharge path of a resistor 225. A pair of diodes 216 and 217 operates to impress a negative bias of about 1.5 volts at the input of an inverter 221, which will cause the output this inverter to assume a logic high state. A capacitor 218 is connected across diodes 216-217. Thus, line 224 is normally at a logic high level.

However, if a voltage inrush condition is sensed, some energy is transferred from capacitor 219 to capacitor 220, which positively biases the input of inverter 221. The output of inverter 221 then switches to a low logic output and quickly discharges capacitor 219 through resistor 222 to ground, as well as sinking any current continuing to be rectified by diode bridge 214. Capacitor 220 discharges much more slowly through resistor 225, keeping the output of inverter 221 at a low state. Line 224 to inverters 226-227 is then kept at a logic low level, as is line 229 to an input terminal of microcontroller 110. This voltage inrush restraint circuit is effective for a wide range of applications. For example, this restraint circuit will perform effectively in a wide range of applications from 69 kilovolt lines down to 2.4 kilovolt lines.

As previously described, a magnetic reed switch 120 may be used to reset the fault indicator. A capacitor 240 and resistor 241 filter line 242 from reed switch 120 to an input terminal of microcontroller 110.

The circuitry shown in FIG. 12B also includes a power supply including battery 38, fuse 230, Zener diode 232, integrated circuit voltage regulator 235 and capacitors 233-234 and 237-239. Zener diode 232 clips any noise on the input line to the voltage regulator. As previously mentioned, the voltage of battery 38 is about 3.6 volts, as at terminal 231. Voltage regulator 235 provides a regulated voltage of about 3.3 volts at terminal 236 for most of the electronic circuitry. However, because of the higher current consumption, LEDs 33-34 and 63-64 operate more efficiently directly from the 3.6 volt battery.

Microcontroller 110 is normally in a standby or sleep mode in which it draws virtually no power from battery 38. For example, microcontroller 110 may typically draw 7 microamperes, or less, from battery 38 or 38a when it is in the sleep mode and about 200 microamperes when it is in the active mode. Such a microcontroller is commercially available from Texas Instruments of Dallas, Tex. under part number MSP430F1232. Sleep states or modes are sometimes also referred to as a power down mode. Microcontroller 110 may, in general, be any microcontroller, microprocessor or programmable controller that has a low current drain, especially in the sleep mode.

It is of course desirable to minimize the current drain on battery 38 to maximize the lifetime of the battery and make it possible for battery 38 to last the expected lifetime of the fault indicator so that the battery never needs replacement. A crystal 251 sets the clock rate for the microcontroller, which may be about 32 kHz.

The LEDs 33-34 and 63-64 are controlled by FETs 256-260, respectively, via lines 276-280 to the gates of FETs 256-260. An additional LED 35, as shown in FIG. 12B, may be implemented on the face of fault indicator 20, if so desired, such as to indicate a temporary fault or any other desired condition. Resistors 246-250 limit the current conducted through each of the LEDs when the associated FET is conductive. Thus, microcontroller 110 can independently control the illumination of LEDs 33-34 and 63-64 by controlling activation of FETs 256-260 on its output lines 276-280. Thus, different permutations or combinations of the illumination of these LEDs are possible besides those disclosed herein.

A photo sensor 173 is connected in series with a resistor 245 and an FET 255. For example, photo sensor 173 may be a cadmium-sulfide cell or a photo-transistor. FET 255 is normally biased off by a line 275 from microcontroller 110 to further conserve battery power. Once microcontroller 110 is awakened, the microcontroller checks the ambient light

level by temporarily applying a bias on line 276 to render FET 255 conductive. Preferably, microcontroller 110 does not sense the ambient lighting conditions until a fault is detected since there is no need to illuminate LEDs 33-34 or 63-64 before then. For example, microcontroller 110 may briefly sample the ambient lighting conditions about once every 15 to 60 minutes after a fault is detected and while the fault detector is in the timed reset mode.

Microcontroller 110 then senses the voltage across photo sensor 173 on line 274. If bright light prevails, photo sensor 173 may have an impedance of about 1000 ohms. Since resistor 245 is about 100K ohms, the voltage across photo sensor 173 and on line 274 to the microcontroller will be near zero. However, if the ambient light level is nearly dark, the impedance of photo sensor 173 may be about 5M ohms. In this instance, the voltage across photo sensor 173 will be near the regulated output voltage of about 3.3 volts. Thus, microcontroller 110 can distinguish between low ambient lighting levels and high ambient lighting levels.

Microcontroller 110 then decides whether to operate LEDs 33-34 and 63-64 in the lower power nighttime mode or LEDs 33-34 in the higher power daytime mode. Of course, the internal LEDs 63-64 only operate in the nighttime mode. FIG. 13 illustrates a preferred illumination pattern for LEDs 33-34 during in the daytime mode. Upon detecting a fault, the battery power is applied to LEDs 33-34 in three pulses of about 100 ms duration, which are separated by about 200 ms of off time. This is accomplished by the microcontroller 110 activating line 276 to apply power to LED 33 and activating line 277 to apply power to LED 34 if the fault indicator has detected a permanent fault. This pattern is then repeated every three seconds for about three times. The fault indicator may then assume a sleep mode for about 3 seconds before again illuminating LEDs 33-34 in the sequence of FIG. 13.

If the fault indicator is operating in the nighttime mode, lower power will be applied to LEDs 33 and 34, as indicated in FIG. 14. In the nighttime illumination mode, each 100 ms pulse in FIG. 13 becomes a plurality of 6 ms pulses separated by 12 ms of off time. Thus, the nighttime illumination mode uses about 33 percent as much power as the daytime mode. Because the human eye cannot see separate pulses of such short duration, the net effect is a dimmer visual appearance to the lower power nighttime illumination patterns. Interior LEDs 63-64 may be similarly powered in the nighttime mode. This pulsed form of supplying power to LEDs 33-34 and 63-64 will further conserve battery power.

Microcontroller 110 may begin illuminating LEDs 33-34 and 64-64 immediately upon detection of a fault or after a predetermined delay since service personnel are not likely to immediately arrive after a fault occurs.

To further save on battery current drain, LEDs 33-34 and 63-64 are preferably not continuously illuminated in either the daytime or nighttime modes. Instead, as shown in FIG. 13, LEDs 33-34 are preferably pulsed on for about 100 ms three times, with about 200 ms of off time between the pulses, with power being enabled to the LEDs only intermittently during the pulses. These pulses are then followed by an off time of about 3 seconds when preferably no further pulses appear. However, this off time is not critical and may generally range from about 2 to 10 seconds. Preferably, this pattern of pulses may be repeated about every 2 to 10 seconds. This provides the eye-catching illumination characteristic desired to call attention to a fault occurrence while further limiting current drain and conserving battery life. Of course, many variations will be apparent to those skilled in the art with respect to the on/off times, such as pulsing LEDs

33-34 on for about five times instead of the illustrated three times, altering the various time periods, and the like.

The previously described nighttime LEDs 63-64 disposed in the interior of housing 30 or 30a may be actuated by biasing FETs 259-260 into their conductive states when microcontroller 110 determines from photo sensor 173 that there is low ambient lighting that will provide housing 30 with a glowing effect if LEDs 63-64 are continuously powered. However, if LEDs 63-64 are intermittently powered or pulsed, such as in accordance with the diagrams in FIGS. 13 and 14, housing 30 will provide a flashing effect.

A connector 285 has a plurality of conductors to microcontroller 110 and to other portions of circuitry 100 to enable programming of microcontroller 110.

The fault indicator 20 preferably has a timed reset to assist in following the path of a fault along the power distribution lines. If the fault indicator reset upon termination of the fault, information about the location of temporary faults would frequently be lost before service personnel could arrive to investigate. Accordingly, once a fault is detected, the fault indicators preferably continue to display the fault condition, such as by LEDs 33-34 and/or LEDs 63-64 for a predetermined amount of time such as from 1 to 24 hours, and preferably about 16 hours. After the predetermined time, fault indicator 20 will automatically reset itself including termination of illumination of any LEDs 33-34 and/or 63-64, termination of sampling of photo sensor 173 and microcontroller 110 will resume its normal sleep mode.

A reset switch 120 has an input on line 242 of microcontroller 110 for manually resetting the fault indicator with a magnetic tool 60 (FIG. 4) at any time. If fault indicator 20 is manually reset, any LEDs 33-34 and 63-64 will be deactivated and microcontroller 110 will return to its sleep mode.

Due to the typical outdoor environmental conditions that the fault indicators 20 are subjected to when installed on the conductors of a power distribution system, 10 years is about the expected lifetime of these fault indicators. Advances in the state of the technology can also be expected to obsolete fault indicators in about 10 years. Thus, the low current drain of circuitry 100 in combination with the high capacity of battery 38a provides a fault indicator 20 in which the battery can be realistically expected to last the lifetime of the fault indicator, without any needed or required replacement of the battery during the operative lifetime of the fault indicator.

FIG. 15 is a flow chart illustrating typical steps that may be employed by microcontroller 110 during its various modes of operation. Initialization occurs at block 300. Any reset conditions are checked at block 301, and the last status of the fault indicator is obtained from flash memory, which may be internal in microcontroller 110. At block 302, a wakeup routine is initiated about every two seconds. Upon wakeup, microcontroller 110 checks for any interrupts, any fault signal, and any inputs from the test switch, calibration switch and A/D sampling of current/voltage. Operation then moves to decision block 303 to determine if a fault is occurring. If so, block 304 initiates the fault handling routine, which is further described below with reference to FIGS. 16A and 16B. If no fault is detected, the operation moves to block 306 where any current inrush or voltage inrush condition is monitored. If any such inrush condition exists, the operation moves to block 306 for initiation of the current inrush or voltage inrush routines. These inrush routines are described in greater detail below with reference to FIG. 17. If no inrush condition exists, operation moves to decision block 307 to determine if the fault indicator is in the test mode. If so, operation moves to block 308 where the test

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handling routine is initiated, as described in greater detail below with reference to FIG. 18. If the test mode has not been selected, operation moves to block 309 for the wakeup and sampling mode, which checks inputs, selects current and voltage and decides whether the fault indicator is in an overhead application or an underground application.

FIGS. 16A and 16B are flow charts illustrating typical steps utilized by microcontroller 110 during the fault handling routine. As indicated in block 320, microcontroller 110 can wakeup within 6 microseconds of any change in input, such as upon the occurrence of a fault. At block 321, microcontroller determines whether the fault indicator is in an overhead application rather than an underground application. If the application is overhead, the process moves to block 322, which determines if a detected fault pulse is greater than 5 ms. This is intended to eliminate noise or transients that might otherwise falsely trigger a fault condition. If not, the process ends at block 323. If the fault is greater than 5 ms, microcontroller 110 activates fault indicating LEDs 33 and 34 in the bright pattern of FIG. 16. After about a one minute delay at block 323, microcontroller 110 rechecks its inputs at block 325. At block 326, microcontroller 110 determines if there is still current in conductor 21. If so, the previously detected fault did not cause a reclosing relay to lockout. Accordingly, microcontroller determines that the fault is temporary and moves to block 332. However, if it is determined that there is no current in conductor 21 at block 326, the process moves to block 327, which checks the voltage on line 132 in FIG. 12A, which is the signal representative of the load current in conductor 21. As previously described, a voltage level of greater than 3.0 volts on line 132 indicates that the selected trip setting is exceeded, but there has been no interruption of power supplied to conductor 21 by a reclosing relay, circuit breaker or the like. Thus, microcontroller 110 determines that the fault is temporary and the process moves to block 332. However, if the voltage on line 132 is not greater than 3.0 volts, microcontroller 110 determines that the fault is permanent at block 328. It then checks the ambient light levels with light sensor 173. If it is daytime, LEDs 33 and 34 flash in accordance with the pattern shown in FIG. 13. If it is nighttime, LEDs 33 and 34 flash in accordance with the lower power of FIG. 14, and interior LEDs 63 and 64 will also be illuminated in accordance with FIG. 14. At block 329, microcontroller 110 checks to see if any reset signal is received, such as from magnetic reed switch 120. If so, the process ends at block 331. If there is no reset signal, block 330 checks to see if 4 hours has elapsed since the fault was first detected. If not, LEDs 33 and 34 (and LEDs 63-64 during nighttime) continue to flash. When the timeout period of 4 hours is reached, the process ends. Of course, the length of the timeout period could alternatively be set at 16 hours.

If one of the LEDs 33 or 34 is used to indicate the occurrence of a temporary fault, and if the fault was previously determined to be temporary at block 332, the ambient light levels are checked with light sensor 173. If it is daytime, the temporary LED flashes in accordance with the pattern shown in FIG. 13. If it is nighttime, the temporary LED and LEDs 63-64 will flash in accordance with the lower power of FIG. 14. At block 333, microcontroller 110 checks to see if any reset signal is received, such as from magnetic reed switch 120. If so, the process ends at block 331. If there is no reset signal, block 334 determines if another fault has occurred, and if so, the process returns to block 322. If no new fault has occurred, microcontroller 110 checks the condition of conductor 21 at block 335 to see if voltage or current is still present on the conductor. If not the

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process ends because the line is dead and no temporary fault continues to exist. If voltage or current is present on conductor 21, block 336 checks determines if timed reset period of 4 hours has elapsed. If so, the process ends at block 336. However, if not, the process returns to block 333.

Returning to block 321, if it is determined that the fault indicator is configured for underground application instead of overhead application, the process proceeds via connector A to decision block 340 in FIG. 16B. If the voltage inrush is less than 3 volts at block 340, the process ends at block 349. However, if the inrush voltage output is greater than 3 volts, microcontroller 110 determines whether the fault pulse is greater than 5 ms in duration. If not, the process ends at block 349. If the fault pulse is greater than 5 ms, microcontroller 110 begins to flash one of the permanent fault LEDs 33 or 34. Only one of the LEDs 33 or 34 is used because the fault indicator 20 is likely to be in a transformer enclosure, or the like, in an underground application. Thus, visibility from a distance is not needed. After a one minute delay, microcontroller 110 rechecks its inputs including the current input at block 343. If there is current in conductor 21, the microcontroller decides that a temporary fault has occurred and the process proceeds to block 350. However, if microcontroller 110 determines that there is no current in conductor 21, the fault is determined to be permanent and the process proceeds to block 346. Microcontroller 110 continues to flash one or both of permanent fault LEDs 33 or 34 in the low power pattern of FIG. 14. Block 347 checks to see if any reset signal occurs. If so, the process ends at block 349. If not, the permanent fault indication continues for the predetermined time out period of 4 hours, block 348, at which time the process ends.

If it was previously determined that the fault was temporary at block 350, the microcontroller activates the temporary fault LED for up to 4 hours. If any reset signal occurs during the 4 hour interval, block 351 will terminate the temporary fault mode at end block 349. If another fault is sensed while in the 4 hour timed reset mode at block 352, the process is sent back to block 340 to again determine the characteristics of the fault. If the fault indicator determines that the line current is restored in conductor 21 at block 353 during the temporary fault mode, the process ends at block 349. Otherwise, microcontroller 110 continues to flash the temporary fault LED until 4 hours is timed out at block 354.

Each time that the microcontroller processes end, such as at end blocks 323, 331 or 349 in FIGS. 16A and 16B, microcontroller 110 terminates illumination of LEDs 33-34 and 63-64 and resets the fault controller to the conditions that existed prior to detection of a fault signal.

The current inrush restraint and voltage inrush restraint routines are shown in FIG. 17. When microcontroller 110 wakes up at block 360, there is a one minute delay at block 361 before the inrush restraint conditions are evaluated at block 362. If current inrush or voltage inrush is detected, the process ends at block 370. This will prevent microcontroller 110 from falsely determining that a fault has occurred if there is current or voltage inrush on conductor 21. If no inrush restraint conditions are detected at block 362, the last trip value is retrieved from flash memory at block 363. If at fault is determined at block 364, the fault routine is initiated at block 365, as already presented with respect to FIGS. 16A and 16B. Otherwise, block 366 determines if the test mode has been selected. If so, the test routine is initiated at block 367, which is presented below with respect to FIG. 18.

The test routines are shown in the flow chart of FIG. 18. After waking up at block 375 and after a 5 second delay at block 376, microcontroller 110 determines if an input has

been received from a test switch to initiate the test routine. If the test switch was activated at block 377, microcontroller 110 flashes LEDs 33 and 34 in the pattern shown in FIG. 13 for three times at block 382. Flashing of LEDs 33 and 34 also confirms that battery 38 has adequate power. It automatically sets the fault indicator for the default 200 A trip setting at block 383 and writes this trip setting in the flash memory. The test procedure then ends at block 381.

The wakeup routine and the overhead/underground routines are shown in FIG. 19. Microcontroller 110 wakes up every 2 seconds as shown in block 395. It then monitors the signal from the electrostatic sensor 145 at block 396. If the fault indicator is configured for an overhead application, the electromagnetic field about conductor 21 will cause differential voltages to be induced in the plates of sensor 145, which will provide a high logic signal at the input to microcontroller 110. Accordingly, the fault indicator will be set to an overhead mode at block 397. However, if the fault indicator is in an underground application, there will be an inappreciable electromagnetic field about conductor 21 and the input to microcontroller 110 will be at a logic low level, which will cause it to be configured for an underground mode at block 398. The routine then ends at block 399.

In accordance with the preferred embodiment of the present invention, FIGS. 20 and 21 illustrate flow charts for manually selecting one of a plurality of trip settings for the fault indicators 20 and 20a shown in FIGS. 1-6. As previously described with reference to FIGS. 12A and 12B, microcontroller 107 selects one of a plurality of available trip settings by activating one of FETs 133-140, and may select a default setting of 200 A, for example. The desired trip setting is selected by placing a magnet near the housing of the fault detector 20, which will cause magnetic reed switch 120 to close. If LEDs 33 and/or 34 are displaying a previously detected fault condition, closing of switch 120 will immediately reset the fault indicator, causing LEDs 33 and/or 34 to terminate their display of the fault condition. As further explained below, continued holding of the magnet near the housing of fault indicator will result in a programming mode to enable selection of the desired trip level. This manual programming of the desired trip level may be done in the field after the fault indicator is installed on a monitored electrical conductor in an electrical distribution system. Of course, this manual programming may also occur at any earlier time, such as when the fault indicator is manufactured or before shipping to a customer who has a specific trip setting specification that is different from the default trip setting.

Turning first to FIG. 20, in the first block 400, initialization occurs. This may include typical initialization functions for microcontroller 110, including its ports, clock, interrupts and the like. Microcontroller 110 also recalls the prior or default trip setting, such as from flash memory that may be located within microcontroller 110, or separately provided. At block 401, the flash memory is then updated with the current status information. Microcontroller 110 then goes into its wakeup mode at block 402. For example, this step may be similar to the previously described wakeup mode at block 302 in FIG. 18. Upon first waking up, the display may be activated at block 403. This will cause one or more of LEDs 33-34 to flash at block 404, which confirms that fault indicator 20 is functional and that battery 38 has sufficient power. The fault indicator will then begin to monitor whether the current in the monitored conductor exceeds the trip level of the fault indicator at block 405. If so, one or more of externally viewable LEDs 33-34 and/or internally disposed LEDs 63-64 will begin to flash to indicate the

occurrence of a fault at block 406. Decision block 407 continues to monitor whether a reset condition has occurred, such as by a timed reset, a return of voltage to the monitored conductor, or a manual reset by closing of magnetic reed switch 120.

If no fault was detected at block 405, the process in the flow chart of FIG. 20 continues to block 408 to determine if the fault indicator is in the program mode. The program mode is initiated by placing a magnet near the housing of the fault indicator to close magnetic reed switch 120. Microcontroller 110 monitors the amount of time that switch 120 is closed. If switch 120 is closed for a predetermined amount of time, such as for more than about five seconds, the program mode will be initiated. The programming mode routine, block 409, is then initiated.

FIG. 21 shows the programming mode routine in greater detail. Upon beginning the routine at block 415, if the magnetic tool 60 is held near the fault indicator to keep magnetic reed switch 120 closed for more than about 5 seconds, LEDs 33 and/or 34 may flash once to indicate the lowest trip value, which is 100 A in this example. If the magnetic tool 60 is removed from proximity to the housing of the fault indicator 20, the fault indicator will then be programmed for the first or lowest trip setting of 100 A and LEDs 33 and/or 34 will flash once to confirm that fault indicator 20 is programmed to the first or lowest trip setting at block 417. The programming routine will then exit at block 427.

However, if the magnetic tool 60 continues to be held in proximity to fault indicator 20, after LEDs 33 and/or 34 flash once in block 416, there will be a delay of a predetermined time, such as about 1.5 seconds at block 418. After this delay, LEDs 33 and/or 34 will flash twice to indicate that the trip level programming is now at the second trip level, which is 200 A in this example. If the magnetic tool is removed from proximity to the housing of the fault indicator 20, the fault indicator will be programmed for the second trip setting of 200 A and LEDs 33 and/or 34 will flash twice to confirm that fault indicator 20 is programmed to the second trip level at block 420. The programming routine will then exit at block 427.

If the magnetic tool 60 continues to be held in proximity to fault indicator 20, after LEDs 33 and/or 34 flash twice in block 419, there will be a delay, such as about 1.5 seconds at block 421. After this delay, LEDs 33 and/or 34 will flash three times to indicate that the trip level programming is now at the third trip level at block 422, which is 400 A in this example. If the magnetic tool is removed from proximity to the housing of the fault indicator 20, the fault indicator will be programmed for the third trip setting of 400 A and one of LEDs 33 or 34 will flash three times to confirm that fault indicator 20 is programmed to the third trip level at block 423. The programming routine will then exit at block 427.

If the magnetic tool 60 continues to be held in proximity to fault indicator 20, after LEDs 33 and/or 34 flash three times in block 422, there will be a delay, such as about 1.5 seconds at block 424. After this delay, LEDs 33 and/or 34 will flash four times to indicate that the trip level programming is now at the fourth trip level at block 425, which is 800 A in this example. If the magnetic tool 60 is removed from proximity to the housing of the fault indicator 20, the fault indicator will be programmed for the fourth trip setting of 800 A and LEDs 33 and/or 34 will flash four times to confirm that fault indicator 20 is programmed to the fourth trip setting at block 426. The programming routine will then exit at block 427.

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FIG. 22 illustrates the above-described timing sequence during the programming routine. After a delay of about 5 seconds, LEDs 33 and/or 34 are activated to flash once, as indicated by reference numeral 431. This indicates that the programming routine is at the first trip setting. If the programming continues, after about a 1.5 second delay, LEDs 33 and/or 34 are activated to flash twice, as indicated by reference numeral 432. This indicates that the programming routine is at the second trip setting. If the programming continues, after about a 1.5 second delay, LEDs 33 and/or 34 are activated to flash three times, as indicated by reference numeral 433. This indicates that the programming routine is at the third trip setting. If the programming continues, after about a 1.5 second delay, LEDs 33 and/or 34 are activated to flash four times, as indicated by reference numeral 434. This indicates that the programming routine is at the fourth trip setting. The duration of the activation and the duration of the off time between activation are not critical. The primary concern is that the activations of the LEDs 33 and/or 34 need to be visibly perceived by the person conducting the programming. As one example, where there is more than one flash created, such as at 432-434 in FIG. 22, LEDs 33 and/or 34 may be activated for about 0.5 second with about 0.5 second off time between the activations.

If the magnetic tool 60 continues to be held in proximity to fault indicator 20, after LEDs 33 and/or 34 flash four times in block 425 for more that about 1.5 seconds at block 428, the programming mode returns to and resumes with the first trip level at block 416. The selected programmed trip setting will be stored in the flash memory for recall, as needed, by microcontroller 110.

While the programming mode was initiated by the magnetism of the magnetic tool, it will be appreciated by those skilled in the art that other means of may be employed such as by an infrared port 113 or by a radio frequency (RF) link 115 in FIG. 11. Similarly, while specific voltage levels were used for the first through fourth trip settings, the trip settings may generally be selected, as desired between about 5 A to 1200 A, or more. Likewise, the number of trip settings, the indication of the present or selected trip setting, and the like, may be modified by those skilled in the art, as needed or as desired. While a microcontroller 110 has been presented above, a microprocessor or any suitable data processor or the like may be employed in its place.

It can also be appreciated that the programming of the trip setting to one of a plurality of available trip settings, as disclosed above, may take about 5 seconds to enter the trip setting programming mode and several more seconds to program the fault indicator 20 to the last or fourth setting. Of course, the time intervals used in the description of the preferred embodiment may be decreased, if desired, for faster programming or other faster means of communicating with microcontroller 110 may be utilized such as an infrared port 113 or RF link 115. Such faster means of programming the desired trip setting may also be desirable for more efficient testing and programming of the trip setting during manufacture.

The programming aspects of present invention may also be extended to other characteristics of fault indicator 20. For example, the timed reset time after a fault is detected may be subject to programming to one of a plurality of reset times, such as 4 hours, 8 hours, 16 hours or 24 hours. The time for response to a fault may also be subject to programming. For example, the fault indicator may be programmed to delay in tripping for 1 ms for an underground application or for 24 ms for an overhead application after initial detection of the

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fault. Programming may also include enabling or disabling the previously described temporary fault mode.

The present invention also makes it economically possible to manufacture a fault indicator that may be programmed to satisfy a customer's specifications for a fixed trip setting. For example, if a customer wants an 800 A fixed value trip setting, a fault indicator of the present invention can be programmed to trip at 800 A and then sent to the customer. That is, one programmable fault indicator can satisfy many differing customer requirements by first programming the fault indicator in accordance with the present invention to the desired trip setting and then shipping it to the customer. This provides economies over making, stocking and selling a wide number of fault indicators with differing specifications in order to satisfy the varying specifications of different customers.

In view of the above disclosure, it may also become apparent to those skilled in the art that fault indicator 20 may be placed in a jig, or the like, during the manufacturing process. The jig may provide a coded signal to the microprocessor 110 to preprogram many of the characteristics of the fault indicator such as the trip setting, the length of the timed reset after a fault occurs (which also corresponds to the amount of time that the display and LEDs are active), the response time of the fault indicator to a detected fault, and whether the temporary fault mode is enabled or disabled. For example, fault indicator 20 may be programmed with a coded signal to a 200 A trip setting, a 1 ms response time, a 4 hour reset or display time, and with the temporary fault mode enabled. Such a coded signal could program these features in a fraction of a second, rather than requiring several seconds or more by manually programming with the magnetic tool 60.

While particular embodiments of the invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made therein without departing from the invention in its broader aspects.

The invention claimed is:

1. A fault indicator for indicating the occurrence of a fault in an electrical conductor, said fault indicator comprising:
 - a housing;
 - a battery at least partially internal to the housing;
 - a display for indicating that a fault condition has occurred;
 - a current sensor for sensing the load current in said conductor, and for providing a load current signal that is related to the load current;
 - a data processor drawing power from the battery, and that is in communication with said load current signal from said current sensor to determine the load current in said conductor, to program the fault indicator to one of a plurality of trip settings and to determine that a fault condition has occurred when the load current exceeds the programmed trip setting.
2. The fault indicator as claimed in accordance with claim 1, said fault indicator further comprising:
 - a memory that is accessed by said microcontroller, whereby said data processor stores the programmed trip setting in said memory.
3. The fault indicator as claimed in accordance with claim 1 wherein said data processor is manually programmable to one of said plurality of trip settings.
4. The fault indicator as claimed in accordance with claim 3 wherein said data processor actuates said display to indicate the trip setting selected during programming of the trip settings.

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5. The fault indicator as claimed in accordance with claim 2 wherein said data processor resets the trip setting to that previously programmed and stored in memory if said conductor is deenergized and the load current is later restored.

6. The fault indicator as claimed in accordance with claim 1 wherein said plurality of trip settings are selected in the range of about 5 amperes to about 1200 amperes.

7. The fault indicator as claimed in accordance with claim 1 wherein said plurality of trip settings are selected from the group consisting of 25, 50, 100, 200, 400, 600, 800, 1000, and 1200 amperes.

8. The fault indicator as claimed in accordance with claim 1 wherein said data processor causes said display to display a fault condition for a predetermined time interval when the load current exceeds the programmed trip setting.

9. The fault indicator as claimed in accordance with claim 3 wherein a magnetic tool is used to initiate the programming to select one of the plurality of trip settings.

10. The fault indicator as claimed in accordance with claim 9 wherein said magnetic tool causes a magnetic switch to change state from open to closed or from closed to open, the magnetic switch in electrical communication with the data processor.

11. The fault indicator as claimed in accordance with claim 10 wherein said data processor senses the change in state of the magnetic switch and initiates a trip programming routine if the magnetic switch remains closed for a predetermined amount of time.

12. The fault indicator as claimed in accordance with claim 11 wherein said trip programming routine starts at a first trip setting and delays before moving to a second trip setting.

13. The fault indicator as claimed in accordance with claim 12 wherein removal of said magnetic tool from proximity to said fault indicator before the trip setting routine moves to a second trip setting will program the fault indicator at the first trip setting.

14. The fault indicator as claimed in accordance with claim 12 wherein said display flashes once to indicate that the trip programming routine is at the first trip setting.

15. The fault indicator as claimed in accordance with claim 12 wherein said display flashes twice to indicate that the trip programming routine is at the second trip setting.

16. The fault indicator as claimed in accordance with claim 1 wherein said fault indicator is programmed to one of the plurality of trip settings after the fault indicator is installed on the electrical conductor.

17. A method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor, wherein said fault indicator includes a housing, a battery, a display for displaying a fault condition, a current sensor and a data processor, said method comprising the steps of:

sensing the load current in said conductor with the current sensor;

providing a load current signal from the current sensor that is related to the load current in the conductor;

providing a plurality of selectable trip settings for said fault indicator;

determining the load current in said conductor based upon the load current signal for the sensor;

selecting one of the plurality of trip settings by initiating a programming routine; and

displaying a fault condition if the load current exceeds the selected trip setting.

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18. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 17, further comprising the additional step of:

storing the selected trip setting in a memory for recall by the data processor.

19. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 17, further comprising the additional step of:

displaying the trip level being programmed during running of the programming routine.

20. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 17, further comprising the additional step of:

manually initiating said programming routine by placement of a magnet in proximity to said fault indicator.

21. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 17, further comprising the additional step of:

resetting the trip setting to that previously programmed and stored in memory if the conductor is deenergized and the load current in the conductor is later restored.

22. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 17, further comprising the additional step of:

flashing the display once to indicate when the programming routine is programming the fault indicator to a first trip setting; and

flashing the display twice to indicate when the programming routine is programming the fault indicator to a second trip setting.

23. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 22, further comprising the additional step of:

terminating said programming routine at the desired trip setting by removal of a magnet in proximity to said fault indicator before said programming routine moves to the next trip setting.

24. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 20, further comprising the additional step of:

causing a magnetic switch to change state from open to closed or from closed to open in response to the magnet being placed in proximity to the fault indicator.

25. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 24, further comprising the additional step of:

sensing the change in state of the magnetic switch from open to closed or from closed to open at the data processor; and

initiating said programming routine to program the fault indicator to one of said plurality of trip settings.

26. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 20, further comprising the additional step of:

programming said fault indicator in a selected one of said plurality of trip settings by removing the magnet from

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proximity to said fault indicator while the display indicates that the programming routine is at the selected trip setting.

27. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 17, further comprising the additional step of:

selecting the trip settings from a range of about 5 to about 1200 amperes.

28. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 17, further comprising the additional step of:

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selecting the trip settings from the group consisting of 25, 50, 100, 200, 400, 600, 800, 1000, and 1200 amperes.

29. The method of programming a trip setting in a fault indicator that detects faults in a monitored electrical conductor in accordance with claim 17, further comprising the additional step of:

initiating the programming routine to select one of the plurality of trip settings after the fault indicator has been installed on said conductor.

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